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2. construction firms
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Technical Assistance Mission No. 23

Report by a group of European experts

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The Organisation for European Economic Co-operation (O.E.E.C.) was constituted in Paris on 16th April, 1948. Its members are Austria, Belgium, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxemburg, the Netherlands, Norway, Portugal, Sweden, Switzerland, Trieste, Turkey, and the United Kingdom. The United States and Canada, although not members of the Organisation, participate in its work. At O.E.E.C's headquarters at the Château de la Muette, Paris, representatives of each of these countries meet to discuss their economic problems and to work out a common plan of action. It has been through O.E.E.C. that the national recovery programmes of the Member countries have been coordinated so as to ensure the most effective use of American aid. Among the measures that European countries have agreed in O.E.E.C. to adopt, have been the liberalisation of trade and payments and the setting up of a European Payments Union.

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Published in June 1952

FOREWORD

It is impossible to thank individually all those persons in the United States and in Europe whose efforts made our Mission to the United States possible.

We should however like to express our gratitude first and foremost to the American taxpayer, whose personal sacrifices provided the funds to cover the entire cost of our Mission's tour in the United States under the Technical Assistance of the Aid to Europe Programme.

Secondly, we wish to thank E.C.A. and especially our Project Manager, Mr. Maurice T. Barnes, who prepared a most detailed programme which was faithfully carried out and who, moreover, spared no effort to facilitate our work.

Lastly, we wish to thank particularly all firms which received us during our tour in the United States.

We deeply appreciated the kindness shown to us by all staff in these firms and their evident desire to make our visit as successful and as pleasant as possible; we should also like to mention particularly that in most cases the heads of these firms did not hesitate to place themselves at our disposal throughout our visit.

The editor of the Report also wishes to express his gratitude to Dr. O.A. Hougen of the University of Wisconsin for his valuable assistance in the preparation of the chapter on the chemical engineer.

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MEMBERS OF THE MISSION

A.H.M. Andreasen (Chairman).	Professor of Chemical Technology.	Royal Danish Technical University, Copenhagen (Denmark).
S.G. Terjesen (Editor of the Report).	Professor of Chemical Engineering.	Norwegian Institute of Technology, Trondheim (Norway).
R.G.F. Bridoux.	Chief Engineer, Construction and Design.	Union Chimique Belge, Brussels (Belgium).
A. Derleres.	Director.	Institute of Chemistry and Agriculture " Nicolaos Canellopoulos " Athens (Greece).
E.L. Ewald.	Technical Assistant to Managing Director.	Reymersholms Gamla Industri A.B., Helsingborg (Sweden).
H.M. Guinot.	Technical Consultant.	Cie. Alais, Froges et Camargue, Paris and Ets. Pingris and Mollet Fontaine, Lille (France).
T.J.J. Hoek.	Director of Chemical Construction.	Staatsmijnen (State Bureau of Mines) Geleen (Netherlands).
V. Manetti.	Director of Construction and Maintenance.	Farmaceutici Italia S.A., Milan (Italy).
K.G.K. Peters.	Senior Professor.	Technical University, Vienna (Austria).
H. Sipkes.	Head of Technological Calculation Section.	Mekog-Ijmuiden (Netherlands).
A.J. Young.	Head of Central Instrument Section.	Imperial Chemical Industries Ltd., London (United Kingdom)

The Mission was accompanied by Mr. Ad. A. Kaufmann, Administrative Officer, O.E.E.C., Secretary to the Chemical Products Committee.

THE AMERICAN FIRMS VISITED

M.W. Kellogg Company.	Chemical Engineering Contractors.	225 Broadway, New York. (Laboratories at Jersey City, New Jersey).
Lummus Company.	Chemical Engineering Contractors.	325 Madison Avenue, New York City.
Foster-Wheeler Corporation.	Chemical Engineering Contractors.	165 Broadway, New York. (Laboratories and pilot plant at Carteret, New Jersey).
Houdry Process Corporation.	Chemical Engineering Contractors.	Marcus Hook, Pennsylvania.
Sun Oil Company.	Oil Refinery.	Marcus Hook, Pennsylvania.
Brown Instruments Division, Minneapolis Honeywell Regulator Company.	Constructors of automatic control and measuring devices.	Wayne and Roberts Avenues, Philadelphia, 44. Pennsylvania.
Leeds and Northrup Company.	Constructors of automatic control and measuring devices.	4901 Stenton Avenue, Philadelphia 44, Pennsylvania.
National Bureau of Standards.	Government institution.	Washington 25, D.C.
Koppers Company, Incorporated.	Chemical engineering contractors and chemical manufacturers.	321 Penn Avenue, Pittsburgh, Pennsylvania.
Alleghany Ludlum Steel Corporation.	Steel producers.	Henry H. Oliver Building, Pittsburgh, Pennsylvania.
Aluminium Company of America.	Aluminium producers.	Gulf Building, Pittsburgh, Pennsylvania.

Babcock and Wilcox Company.	Chemical equipment manufacturers.	Barberton, Ohio.
Podbielniak Incorporated.	Chemical equipment manufacturers.	341 East Ohio Street, Chicago, Illinois.
A.O. Smith Corporation.	Chemical equipment manufacturers, including glass-lined equipment.	3533 North Twenty-Seventh Street, Milwaukee, Wisconsin.
General American Transportation Corporation.	Transportation specialists and equipment manufacturers.	135 South La Salle Street, Chicago, Illinois.
Chicago Bridge and Iron Company.	Constructors of tanks and spherical vessels for the chemical industry, etc.	Room 2492, McCormick Building, 322 Michigan Avenue, Chicago, Illinois.
Pfaudler Company.	Equipment constructors, particularly glass-lined equipment.	1000 West Avenue, Rochester, New York.
Stone and Webster Engineering Corporation.	Chemical engineering contractors.	49 Federal Street, Boston, Massachusetts.
E.B. Badger and Sons Company.	Chemical engineering contractors.	75 Pitts Street, Boston, Massachusetts.
Bird Machine Company.	Equipment manufacturers.	South Walpole, Massachusetts.

INTRODUCTION

The Mission

At its 94th meeting held on 4th May, 1950, the Council of the Organisation for Economic Co-operation (O.E.E.C.) decided to dispatch a Technical Assistance Mission on chemical equipment to the United States.

The programme of work for this Mission was drawn up on 24th May 1950, by a Group of Experts appointed by the Chemical Products Committee of the O.E.E.C. It covered the following main points :

a) A general study of the methods employed in the design and construction of chemical installations.

b) A special sample study of the methods employed in the development and utilisation of control instruments, of the special maintenance methods employed in the chemical industry, and of the resistance of the various materials of construction to chemical agents.

In formulating these two main points, the Group of Experts further emphasized the following aspects :

a) A study of chemical engineering.

b) A study of the functions of a " job engineer ".

c) A study of pilot plants.

d) A study of standardisation in chemical equipment.

e) A sample study of individual technical problems such as : design and manufacture of automatic control and measuring instruments, resistance of various substances to chemical agents, apparatus for distillation, absorption, crystallisation and centrifugation; use of high vacuum; use of high pressures; transport of gases and liquids, transport and handling of heavy chemicals; study of maintenance methods.

On the basis of these suggestions, E.C.A. drew up a programme for the Mission extending over the period from 27th September to 31st October 1950. A study of the itinerary given in Annex I to this report will reveal that the E.C.A. took pains to draw up a programme which would permit the Mission to fulfil the tasks set by the Chemical Products Committee of the O.E.E.C.

Immediately on arrival in New York the Mission was welcomed by Mr. M. T. Barnes, who travelled with it as project manager. His able handling of the travelling arrangements, his determination to see that the maximum benefit was obtained from the visits, and his efforts to give the members a wider understanding of the United States and their people were invaluable.

Everywhere the Mission was most cordially received, usually by the presidents or vice-presidents of the companies visited. First-class experts were generally placed at the disposal of the Mission, and questions were answered willingly. The Mission was frequently entertained to luncheon or dinner and valuable opportunities for further discussion were thereby provided.

The report

Plan

This report gives information obtained by the Mission on a number of developments which have taken place in the United States during the last ten to twenty years. The information cannot be claimed to be new because it will naturally be already known to at least some European experts through technical journals and previous visits to the United States.

Special emphasis is laid as far as possible on those developments which can be considered to be entirely or mainly American, but in many cases information about corresponding European developments is not available, and the Mission is not in a position to judge to what extent any particular development is due to American enterprise.

Conditions differ from one European country to another, and perhaps even more widely within each country; it will almost invariably be found that the more progressive firms in Europe have already introduced these new techniques which have been developed in America and which can be applied to their own conditions, whereas the less progressive firms still have many important lessons to learn from the successful development of the chemical industry in the United States.

An attempt has been made to focus attention on those developments which have proved, or may well prove, to be significant in the industrial field and thus help the reader to separate the good from the indifferent in the enormous amount of material published on the subject.

The report consists of four main parts :

a) The first four chapters are general and deal with chemical engineering, its applications, and the methods employed in the United States to develop new processes and employ them on an industrial scale with maximum efficiency and speed and with minimum capital expenditure.

b) Specific chapters (Chapters V to XI) describe the various manufacturing methods which the Mission studied in the

United States, and which are little known in Europe, or if known, are little used.

c) The last chapter consists of a general discussion and the general conclusions reached as a result of studying American working methods and conditions.

d) The Appendices contain more specific information expected to be of interest to a more limited number of readers.

It is important to note that this report only contains an account of what the Mission was able to see and hear and the conclusions it reached during its brief visit. It cannot therefore be regarded in any way as an exhaustive treatise on the subjects dealt with, but rather attempts to contribute to a better European understanding of the working methods followed in the United States.

Contents

It is apparent that in the chemical and petroleum industries in the United States, after a relatively modest start, have attained in less than 40 years a leading position in productivity and in the range and volume of output of many important products. It is vitally important for the European chemical industry to inquire into the reasons for the much slower development in Europe and, if possible, to devise means of competing on equal terms in future.

The special features of the American chemical industry have therefore been reviewed, and the possibilities of applying selected advanced methods and techniques to European conditions discussed. Particular emphasis is laid on the training and functions of the chemical engineer and the outstanding services rendered by the many firms of chemical engineering contractors, the manufacturers of instruments, equipment and materials of construction, and the transport specialists. Advanced procedures and designs for catalytic processes, the separation of homogeneous mixtures and heat exchange are dealt with, and some recent developments in agitation, drying, filtration, classification and centrifugation are mentioned.

The structure and organisation of the American chemical industry is considered as a whole and in individual units.

An attempt is made to show how the progressive attitude adopted in America is leading the chemical industry forward from one success to another, and how the Americans consciously strive to encourage and maintain this progressive attitude. Evidence of this can be seen in many ways such as :

a) Ensuring that progress is rewarded, and that opportunities for gaining reward are open to all.

b) Organising activities on a " specialist " basis, and providing advanced courses for training the specialists required.

c) Extensive employment of highly trained technicians and

advanced personnel management with incentive schemes and extensive delegation of authority.

d) Emphasis on application engineering and commercial exploitation.

e) Willingness to try out new ideas and to replace old out-of-date conceptions when new ones have proved their value.

f) Willingness to subcontract and to put efficiency before self-sufficiency and prestige.

g) Wide circulation of general chemical engineering information.

h) Adoption of the principles of standardisation and simplification as general rules for reducing costs.

PART I

I

THE CHEMICAL ENGINEER

The rise of a profession

In the complex organisational network of the chemical industry the Americans have created a new and most important professional link : the chemical engineer. The profession of chemical engineering was first defined in Europe in the second half of the last century and a short-lived society of chemical engineers was established in London in 1880. The profession did not, however, begin to assume importance until it was generally realised in the United States, some 40 years ago, that chemical engineering, as a separate branch of engineering, requires its own separate university curriculum. Chemical engineers, in the modern sense of the word, scarcely existed 25 years ago.

The definition of the chemical engineer

The discovery that the multitude of widely differing chemical manufacturing processes are essentially composed of a relatively small number of unit operations such as drying, evaporation, distillation, absorption, etc., together with heat transmission and fluid flow, made it possible to define the central field of chemical engineering and to provide a systematic method of instruction based upon fundamental principles rather than upon a description of separate industries. The chemical engineer is primarily concerned with the industrial application of the physical and chemical changes of material through the theories of unit operations and applied chemical kinetics. The chemical engineer is neither a chemist with some knowledge or engineering, nor a mechanical engineer with some knowledge of chemistry, but a new type of engineer with a field of activity of his own. The American Institute of Chemical Engineers has recently adopted the following definition of chemical engineering :

> " Chemical engineering is that branch of engineering concerned with the development and application of manufacturing processes in which chemical or certain physical changes of material are involved. These processes may usually be resolved into co-ordinated series

of unit physical operations and unit chemical processes. The work of the chemical engineer is concerned primarily with design, construction, and operation of equipment and plants in which these unit operations and processes are applied. Chemistry, physics and mathematics are the underlying sciences of chemical engineering, and economics its guide to practice ".

The need for the chemical engineer

The increasing complexity of the chemical industry has made it impossible to leave it to the chemist and the mechanical engineer between them to develop, design and operate chemical plants. The interests of the chemist are centred on chemistry and those of the mechanical engineer on mechanical design and construction. Their fields of interest are entirely different and there is little mutual comprehension. The previously neglected no-man's-land between them now constitutes the domain of the chemical engineer.

The need for chemical engineering may be illustrated by a consideration of the steps involved in the transfer of a new process from the laboratory to the commercial plant. The mechanical engineer, through the limitations of his training, would tend to adopt the false but common procedure of enlarging the beakers and flasks used by the research chemist in direct proportion to the rates of output and thus to design a plant consisting chiefly of large tanks and reaction vessels all operated batchwise. This procedure ignores the principles of physical and chemical change. The chemical engineer, on the other hand, has the necessary background for understanding all the intricacies of the chemistry of the processes, the principles governing the operation of the equipment and the economics of plant operation. He is therefore in a position to act more boldly and, departing from the beakers and flasks of the laboratory, to design plants and processes which best satisfy the exacting requirements of science, engineering and economics.

Examples of satisfactory plant designs resulting from the co-operation of pure chemists and mechanical engineers can, of course, be quoted, particularly in Europe, but these projects have usually been handled by mechanical engineers who have such extensive experience of chemical engineering that they should be classed as chemical as well as mechanical engineers.

There can be no doubt that the field of chemical engineering is clearly defined and distinct from that of both chemistry and mechanical engineering. The chemist cannot cover this field because it is difficult for him to acquire an engineering outlook. The mechanical engineer could through experience and further study acquire the necessary skill for dealing with the physical changes involved in the unit operations, but when it comes to the application of the theory of chemical change to the design of reactors he lacks the necessary background. The physicist masters the fundamental theory, particularly where physical changes are involved, but he usually lacks the engineering outlook, and has shown

little aptitude for combining strict theory with semi-empirical procedures, a combination which forms the necessary working tools of the chemical engineer. Separate university courses are clearly essential if industry is to secure chemical engineers with proper training. Increased specialisation is widening the gap between the chemist and the mechanical engineer and making the need for the chemical engineer even more urgent.

The functions of the chemical engineer

From his college training and subsequent industrial experience the chemical engineer has acquired a background which will enable him to perform a variety of functions in the chemical industry. The most important of these are :

Research and development.
Process design.
Equipment design.
Plant operation.
Laboratory testing.
Technical service and sales.

Research and development

The general chemical basis of the processes is usually provided by the organic or inorganic chemist, and the data on chemical and physical equilibria by the physical chemist. Neither of these, however, is trained to obtain data on the important question of heat exchange in flow systems. It is necessary for the chemical engineer to engage in process research in order to obtain proper and adequate data on the variations and properties of the system, as these are essential to economic design and operation. The chemical engineer is in a better position to plan laboratory work and to secure results applicable to plant design. As an illustration, a laboratory batch experiment, if intelligently planned, properly carried out and skilfully interpreted, can often yield sufficient data for the design of a continuous plant. With his knowledge of plant and process economics the chemical engineer is also well equipped for the task of selecting the research and development projects most likely to give technical and commercial results.

Pilot plant work

One of the most important decisions facing the chemical engineer is whether or not a process should be tested in a pilot plant. The cost of pilot plant work in time and material is so great that such studies should not be undertaken if the information required can be obtained in any other way. As a result of recent developments in applied chemical kinetics, combined with the principles of mass and heat transfer, the large-scale performance of equipment can in some cases be predicted with reasonable confidence from data obtained in the laboratory.

If pilot plant work cannot be avoided, the chemical engineer should determine exactly what points need clearing up and design the pilot plant specifically to provide the information required.

Process design

The chemical engineer is alone responsible for process design, and this duty he should not delegate to others. By process design is meant the calculations involved in determining the size of reactors, heat exchangers, absorption towers and extraction columns, in ascertaining the optimum conditions of operation as to temperature and pressure, feed composition, mass of catalyst required per unit weight of feed, extent of recycling, etc. Based on the results obtained in the laboratory or from the pilot plant these problems can be solved from the principles governing the chemical processes and from the principles of dimensional similitude. The result of this work is embodied in the flow chart and in the process description. The information should be adequate to serve as a basis for the mechanical design of the equipment.

Screening of data

The chemical engineer responsible for process design collects his data from many sources. He must make sure that these data are reliable, adequate and applicable. It is often more difficult to secure correct data than to carry out the design calculations. The chemical engineer is only part of a team where all the members are responsible for the success or failure of the project, yet his position and background of training and experience leave him with the major responsibility for screening and analysing the assembled data. He must test these data by means of the laws of nature, accepted methods of correlation and published information. He must pay particular attention to the formation of by-products, a question which often escapes detection on the laboratory scale.

Equipment design

The distinction between process design and equipment design is sharply drawn. Equipment design involves the mechanical details of construction and calls for a full knowledge of mechanics, the strength of material, the lay-out and selection of piping and pumps, the detailed drawings for plant lay-out, the specification of safety devices and the instrumentation of the process. This work can be undertaken either by the chemical or the mechanical engineer.

Usually equipment design should be carried out by a specialist in equipment manufacture, and should not be regarded as an incidental task of a plant chemical engineer. Instrumentation has also become a speciality and large installations are handled by instrument manufacturers, especially where extensive electronic controls are involved.

The job engineer

In the large American chemical engineering organisations the various design projects are handled by a number of different teams specialising in such fields as process design, design of pressure vessels, heat exchangers, piping, electrical installations, structures, instruments, expediting, erection and start-up. These specialists are concerned with a number of different projects simultaneously, and to secure the necessary co-ordination a so-called job engineer is assigned to each project. With his understanding of the chemical principles and unit operations involved, the chemical engineer is eminently suited to fill this strategic position. The function of the job engineer is to supply the design engineers with the required information, to ascertain that the equipment designed actually fulfils both the process requirements and the customers' wishes, and to see that the time-limits set by the contract are observed.

Although the job engineer obviously plays a leading part in design work, it is important that he should consider himself only as an ordinary member of a team, even though his training and experience have placed him in the centre of the organisation. The credit for a good job should be shared by all members of the team from the research chemist to the construction engineer.

Dangers of specialisation

The efficiency of the American industrial machine is to a great extent due to extreme specialisation. The field of chemical engineering is too wide for any one individual to possess first-hand knowledge of all its applications. It follows that if a chemical engineer is to become an expert, he must inevitably become a specialist. On the other hand, the industry requires administrators and co-ordinators with a broad engineering background coupled with common sense and a balanced outlook. The more progressive firms counteract the dangers of specialisation by moving their most promising young chemical engineers round the various sections dealing with research and development, process and equipment design, erection, and plant operation. Large manufacturing companies which cover all these functions should have no difficulty in carrying out such a policy. The large firms of chemical engineering contractors, on the other hand, do not themselves operate chemical plants, and have difficulty in giving their chemical engineers sufficiently wide experience. Contrary to the general policy of personnel management, these firms often recruit key chemical engineers outside their own organisations.

Chemical engineering education

The responsibility for producing chemical engineers trained for the duties described above rests with the universities, the technical institutes and with the industry itself. In the academic institutions the student can acquire a background of theoretical knowledge but not practical

experience. In both process and equipment design the best advanced vocational training is provided on the job.

The beginning and the development of vocational training

Chemical engineering education in the modern sense of the term began in 1923 with the appearance of the first standard textbook on the subject, entitled " The Principles of Chemical Engineering " by Walker, Lewis and McAdams. This book presented concisely and clearly the principles of the various unit operations. Experimental data for the application of these principles were largely lacking, but have gradually been accumulated, particularly through doctorate theses in chemical engineering, and assembled from time to time in Perry's " Chemical Engineer's Handbook ". The foundations for an effective university training have thus been provided.

Fundamental principles of chemical engineering education

Chemical engineering education in the United States has always striven to serve first the needs of industry rather than the advancement of pure science. At the university the student is obliged to develop empirical procedures wherever the data and principles of pure science are inadequate or where the operating conditions of chemical processing are too complicated to be resolved into any known combination of elementary principles.

The student must also realise that chemical engineering is not a bookish profession, nor is it likely to become one. The combination of the many principles of chemistry, physics and mathematics with the multiple requirements of chemical processing is too complex for handbooks, and must be left to the ability and imagination of the chemical engineer for each particular assignment. Furthermore, the numerical constants associated with each chemical process usually have to be determined from independent experiment. Rarely will complete numerical data suitable for a particular process design be found in literature.

It is noteworthy that the old types of courses in industrial chemistry are disappearing in the United States. This subject has become so complex that the teachers cannot give the students anything but a fragmentary notion of the processes actually being used in the American chemical industry today; neither does the subject lend itself to the study of modern processes and the principles governing them.

It is not very satisfactory to discuss subjects such as material and energy balances in a description of the various processes used in the chemical industry. There is a very great danger that fundamental principles such as material and energy conservation and the way to apply them may be misunderstood if they are presented to the student along with a mass of detail which he will never be able to retain. Despite all the detailed information which industrial chemistry courses may

provide, they remain superficial and of practically no value to the student. The change in the treatment of the subject can best be demonstrated by the fact that nowadays duly selected processes illustrate the application of fundamental principles, whereas formerly such principles were explained in a description of industrial processes. To some extent the disappearance of the standard courses in industrial chemistry from the chemical engineering curriculum has inevitably prevented the teaching staff from giving the students the full benefit of their personal experience in particular sectors of industry. An attempt has been made to eliminate this disadvantage and give new impetus to industrial chemistry courses by introducing the concept of unit processes. Processes such as chlorination, sulphonation, oxidation, hydrogenation, nitration, amination, etc., are discussed as such, without reference to the previous and subsequent processes with which they are connected in any industrial manufacture. For the chemical engineer, this division into unit operations may seem superficial, for however different operations such as oxidation with oxygen gas, chlorination and hydrogenation may be chemically, they all imply the reaction of a gas with a liquid and therefore bear a greater physical resemblance to each other than oxidation with air does to oxidation with a liquid oxidiser. At the present time a more logical method is being developed, based on the transfer properties of the system and the principles of reaction kinetics.

The curriculum

A modern chemical engineering curriculum in the United States is divided approximately equally between the following groups of subjects :

Chemical engineering.
Other engineering, including drawing.
Chemistry.
Science other than chemistry.
Humanities and other outside subjects.

In chemical engineering subjects it is considered desirable that there should be separate courses in :

Applied stoichiometry (material and energy balances).
Unit operations (with laboratory instruction).
Chemical engineering thermodynamics.
Instruments and automatic control (with laboratory instruction).
Materials of construction.
Equipment design.
Plant projects (with calculation and drafting).
Applied reaction kinetics.

It is generally considered essential that courses in applied thermodynamics should be given by a member of the chemical engineering faculty so that the subject may be taught from the practical rather than from the usual theoretical and historical approach. The syllabus should be based on practical applications and not on scientific interest.

The modern trend in chemical engineering education in the United States is to stress the chemical aspects involved in reaction kinetics as well as the physical aspects involved in unit operations.

Importance of numerical problems

Instruction in chemical engineering should be quantitative rather than descriptive, and the students should spend much of their time applying their knowledge to the solution of numerical problems often involving economic elements. The aim should not be to impart the greatest quantity of knowledge to the students, but rather to teach principles and their application and to explain how to find the necessary technical information.

Specialisation

It is also considered important to avoid all specialisation in the undergraduate curriculum. The course should be fairly general and devoted mainly to principles.

Laboratory instruction

Engineering laboratories for the study of unit operations and selected chemical processes with small-scale plant equipment are considered essential in America for satisfactory chemical engineering training. In order to save time, experiments on unit operations and instrumentation are generally set up permanently, ready for the students to operate, and thus tend to be of a routine character. This undesirable feature is offset by additional experiments in chemical processing or research where there is greater scope for the students to exercise initiative, ingenuity, and imagination.

Although it is generally realised in Europe that semi-industrial laboratory instruction is essential in a chemical engineering curriculum, many European universities offering such courses do not have adequate laboratory facilities. It is essential that this defect be remedied without further delay.

Training in team work

The central position occupied by the chemical engineer in design and development projects demands exceptional personal qualities and a capacity for team work. For this reason, training in team work is generally introduced at the undergraduate stage. Most of the assignments in plant projects and laboratory work on unit operations and semi-industrial processing are too large to be handled by the students individually. For these assignments the students are organised in groups which, however, should be restricted to the minimum required for carrying out the task in hand effectively.

The M.I.T. practice school

The Massachusetts Institute of Technology operates a practice school which deserves special mention, although it is not typical of American chemical engineering education. The practice school has three stations located at industrial plants and one at an atomic energy establishment. In charge of each station is a full-time faculty member who formulates the problems. The work is planned solely to give the maximum educational benefit to the students, and any advantage to the firms concerned is entirely incidental. The faculty member lives in a hostel with the students and is always available for guidance and help. The students spend about two months at each of three stations working in teams of three. The student leader changes when the team moves on to another station in order to give each the opportunity to serve as leader. At the end of each stay the faculty member assesses the students, and even more important, the students themselves assess each other, on personal qualities as well as professional ability. At an early professional age the prospective chemical engineer is told by his fellows where he is lacking, and thus will make serious and successful attempts to improve.

The practice school is generally open to post-graduate students only. This school has undoubtedly a high educational value, but it is expensive to operate and cannot therefore be copied extensively either in the United States or in Europe.

Length of courses

The ordinary undergraduate course is scheduled for 4 years but on average about 4 1/2 years is taken to complete it. Students matriculate at about 18 years of age and graduate at about 22 to 23 with a B.Sc. degree. Thereafter one additional year is required for the M.Sc. and 3 additional years for the Ph.D.

Post-graduate studies

Between 10 and 30 % of chemical engineering graduates proceed to post-graduate studies. At undergraduate level 10 % of the engineering students are in the chemical engineering department, but at the graduate level this figure jumps to 20 %. It is common practice for the graduate to serve some years in industry and then return to a university for further study. This is an excellent practice which should be generally encouraged in Europe.

Almost without exception study for a doctorate in the United States is assisted by some type of research grant rather than paid by the student himself. The doctor's degree in chemical engineering is granted by only a few universities.

ACCREDITING DEPARTMENTS OF CHEMICAL ENGINEERING

The rapid development of chemical engineering education in the United States is in no small measure due to the influence of the American

Institute of Chemical Engineers, the Engineering Council for Professional Development and the Chemical Engineering Division of the American Society of Engineering Education through their accrediting activities. An accrediting committee is appointed, consisting of an equal number of members from industry and from the teaching profession. The object of accrediting is to ensure the attainment and maintenance of minimum standards.

Uniformity not compulsory

The qualifications for an accredited curriculum in chemical engineering have been prepared by the Accrediting Committee of the American Institute of Chemical Engineers and are set out in Annex II to this report. This document gives an excellent account of the American view of chemical engineering education. It is explicitly stated that there is no intention of making the curricula uniform or of establishing a fixed pattern. Certain minimum standards are demanded without insisting on uniformity. The minimum standards cover the ability, training and achievements of the staff; the subjects in the various courses; minimum laboratory and library facilities; the course content in unit operations, thermodynamics, instrumentation, process design, and the availability of practical courses. There should be little or no specialisation in undergraduate work. The teaching load should not be too heavy, so that the staff may be free to undertake a substantial amount of research and consulting work, and play an active part in professional societies.

Separate department of chemical engineering

It is generally recommended in the United States that chemical engineering should form a separate department in the engineering school and not be treated as a department of chemistry. The chief reason for maintaining a separate department is to be free to develop technical courses and to select problems of research closely related to the immediate needs of industry rather than to the theoretical problems of pure science. Although close collaboration between pure and applied science is essential for the advancement of both, the best opportunity for independent growth seems to be provided by separation. However, in a few institutions a common administration has worked out successfully.

THE EMPLOYMENT OF THE CHEMICAL ENGINEER IN AMERICAN INDUSTRY

The total membership of the A. I. C. E. comprises about 10,500 fully qualified chemical engineers. About 50 % of these are under 30 years of age, illustrating the rapid growth and the youth of the profession.

Decline in graduates

In 1950 about 5,500 young chemical engineers graduated in the United States. It is estimated that the number will fall to about

3,800 in 1951, 3,100 in 1952 and in 1953 will probably not exceed 2,000. This decline is common to other branches of engineering, and is due simply to the passing of the post-war " hump " of ex-Service students and to the recent call-up of younger men for military service. There is no lack of demand — rather fear of a serious shortage of trained men in the years to come. One remedy suggested by the Secretary of the A. I. C. E. is that " consideration should also be given to the training of women for positions in the engineering field which they are qualified to fill ".

Types of employment

The proportion of chemical engineers employed on different types of work is shown in Table I; prepared by the National Roster of Scientific and Specialised Personnel. It is not only difficult to differentiate sharply between the various functions of the chemical engineer, but even more difficult to distinguish between strictly chemical engineering work and work based on allied activities.

Table 1.

DISTRIBUTION OF CHEMICAL ENGINEERS BY OCCUPATIONAL FUNCTIONS

	PERCENT
Research and development	30.6
Production, operation and maintenance	22.1
Management and administration	10.5
Inspection, testing, process control	7.9
Design, construction, installation	6.5
Technical service and sales	2.9
College and university teaching	1.6
Consulting	0.6
Estimation and specification writing	0.6
Technical writing and editing	0.5
Others	16.2
	100.0

The predominance of research and development is noteworthy. This is still another instance of the importance attached to applied research in the United States.

The distribution of the chemical engineers on the National Roster according to sources of employment is shown in Table 2. About 90 % of the civilian records examined are accounted for in this table, the rest representing a small number of industries each employing a few chemical engineers.

Table 2. Sources of employment of chemical engineers (as of January 1st, 1945)

	PER 1,000 REGISTERED ENGINEERS
Chemical process industries :	
Industrial chemicals	225
Petroleum refining	131
Explosives	40
Plastics	38
Rubber products	34
Paper and allied products	26
Synthetic rubber	25
Food products	22
Non-ferrous metals	22
Drugs and insecticides	20
Glass, cement, clay, abrasives	19
Iron and steel	18
Paints, varnishes and colours	17
Oils, soap and glycerin	17
Rayon, and synthetic fibres	12
Other industries :	
Machinery	35
Contracting	16
Instruments	15
Aircraft	14
Ordnance	10
Wholesale and retail trade	10
Non-profit research agencies	6
Private practice	6
Government agencies	82
Educational institutions	26

This table indicates a wide distribution of chemical engineers in American industry, even in sectors not normally classified as chemical.

Comparison with European conditions

Why did the profession of chemical engineering develop in America and not in Europe?

There is much to be learned from the reasons for the growth of chemical engineering in America rather than in Europe, despite the fact that its development was clearly foreshadowed in Europe at least 70 years ago. The first reason is the greater appreciation of the importance of applied research in the United States, which fostered the development of the profession.

Up to 1916 the United States had very little chemical industry whereas Europe had a considerable output of chemical products. The gradual development of these industries in Europe over a long period made it possible for the industrial chemist and the mechanical engineer to adapt themselves sufficiently to handle the relatively simple projects of that time. This mutual adjustment was aided by the technical Universities which provided good courses in industrial chemistry with a liberal sprinkling of mechanical, electrical and civil engineering for the chemist and excellent courses in heat engineering including heat transmission, evaporation etc. for the mechanical engineer. The great European achievements in the chemical industry, such as the important Solvay, Haber-Bosch and Fischer-Tropsch processes, to mention only a few, leave no doubt as to the success of this development. The European chemical industry can point to many highly important developments in recent times too, but practically all these are achievements in the field of chemistry rather than chemical engineering. The old European tradition of relying entirely on the combination of the industrial chemist and the mechanical engineer seems outmoded and has now become a vested interest tending to stifle chemical engineering progress in Europe. This statement is borne out by the fact that practically all important new developments in chemical engineering such as the fluidising technique, extractive distillation, hypersorption, and the centrifugal extractor, have been evolved in America although most of them were foreshadowed in Europe. It is also highly significant that practically all the important correlations constituting the working tools of the chemical engineer have been established in America.

In the United States chemical engineering became a necessity in the petroleum industry where the skill of the chemist and the mechanical engineer alone proved insufficient to solve the extremely difficult technical problems arising from the vast and rapid expansion of the industry. The significant fact, however, is that the need for chemical engineering was generally recognised and that sufficient funds were made available for establishing university courses in chemical engineering, and, equally important, for carrying out the enormous amount of research work required to establish the data and correlations which form the basis of the professional work of the chemical engineer.

Europe must learn that established traditions in the chemical industry cannot be allowed to hamper progress, and that substantial investments in chemical engineering education, research and development pay high dividends.

Application to European conditions

The objection is often voiced, particularly in the smaller countries of Europe, that most industries are too small to afford a new specialist such as the chemical engineer. This objection rests on a misapprehension because the chemical engineer is in fact the most versatile of all engineers since his basic training includes chemistry, physics and mathe-

matics. If a small chemical firm can afford only a single engineer, a chemical engineer should be chosen. The difference in the size and organisation of the chemical industries of America and Europe does not make the chemical engineer any less useful in Europe.

Chemical engineering education in Europe

Some European universities have recently established separate courses in chemical engineering, and others have introduced courses in unit operations into their industrial chemistry curricula. In most cases chemical engineering is taught in the chemistry department, and the staff and laboratory facilities are often inadequate for satisfactory teaching and research activities.

It is essential that industry should recognise the importance of chemical engineering and that the necessary funds for education and research should be made available by the European governments and industries.

Conclusions

1. The leading position in the chemical industry which the United States has acquired in recent years is to a great extent due to the rapid development of the profession of chemical engineering.

2. The importance of chemical engineering is generally recognised by the government and by industry in America, but this is less frequently the case in Europe.

3. Chemical engineers are employed to a much greater extent in industry in America than in Europe.

4. In the United States a large number of chemical engineers are engaged in research and development.

5. The accrediting activities of the American professional societies have greatly aided the development of chemical engineering education in America.

6. Very few, if any, of the European schools of chemical engineering can at present fulfil all the requirements of the American accrediting committees.

7. A higher proportion of chemical engineering students carry out post-graduate research in America than in Europe.

8. In America many chemical engineers, including those who have already entered industry, return to the university to study for higher degrees.

CONSIDERING that the attention of the governments and of industry should be drawn to :

a) the necessity for chemical engineering education and practice;

b) the value of chemical engineering research;

the Mission recommends :

1. Additional university chairs in chemical engineering should be established in Europe, adequate teaching and research staff appointed and adequate laboratory facilities provided.

2. Scholarships for post-graduate research should be provided on a more liberal scale than at present, particularly by industry.

3. Graduates who have already done outstanding work in industry should be encouraged by the offer of fellowships to return to their universities for further study.

II

CHEMICAL ENGINEERING AND CONSTRUCTION FIRMS

Field of activity

Plant and process design

The Mission visited a number of very large firms of chemical engineering contractors engaged on development, design and construction of complete plants for the manufacture of chemical or petroleum products. These firms were : Badger and Sons, Blaw Knox, Foster Wheeler, Houdry, Kellogg, Koppers, Lummus, and Stone and Webster. Many of these firms are equipped to handle the development of a new process from the laboratory stage to the final commercial plant, but their decisive contribution is generally in the field of engineering. Not all the firms visited carry out pilot plant work themselves, but they will at least offer to assist their customers with the design of pilot plants and with the interpretation of the results. On the basis of pilot plant work carried out either by themselves or by their customers, they design the commercial plant and work out an economic estimate of the project in co-operation with their customers. Most of these contractors also order the plant components, despatch the orders, erect the plant and start it up. The fabrication of the plant components is mostly left to sub-contractors although some of the firms have large factories of their own. It was generally considered advantageous for the main contractor to remain free to place the orders wherever the most suitable and least expensive equipment can be obtained.

Development work

Some firms also develop new processes and techniques on their own initiative rather than at the request of a customer. Examples of such processes are the Houdry catalytic cracking process and the Solexol extraction process. Some firms even engage in the manufacture of such commodities as catalysts and polymerised trifluoro-chloro-ethylene, but on the whole these activities are of little importance compared with chemical engineering design and construction. Some of these firms also hold very large contracts relating to the development of atomic energy.

Size

In the United States there are about half a dozen large firms of this type and 25-30 smaller ones. One of the largest firms visited by the Mission claimed to handle annually projects estimated to cost about $ 200 million. These figures clearly show the importance of these firms in the industrial life of the United States.

Activities in Europe

Several of the firms visited hold large European contracts and have branch offices in many European countries, particularly in Britain, France and Germany.

Before the war the plants were designed and the equipment manufactured in the United States, but the present shortage of dollars has made it necessary to carry out as much of the work as possible in Europe, including a large amount of detail design. Practically all process work and fundamental design work is, however, still carried out in the United States. One firm stated that of the actual construction costs about 75 % could now be paid in European currencies and only 25 % in dollars.

RAISON D'ÊTRE

Opportunities in the petroleum and allied industries

These firms of contractors have been most successful in oil refining and allied industries. The reason is that the projects in this field are usually too large to be handled by the refiner's own engineering staff. The refiner is reluctant to expand his staff for one job only, as this would entail dismissing engineers when the project is completed, with resulting disturbances in employment relations, pensions scheme, etc. It would also be very difficult to secure a sufficiently highly qualified technical staff at short notice. The firms of contractors, on the other hand, have built up a highly competent and specialised team over a period of years.

As an illustration of the limited capacity of the engineering staff normally maintained by an oil refinery, it may be mentioned that a large refinery visited by the Mission can only handle new construction work up to 5 % of present installations. Any major expansion would inevitably require outside engineering facilities. Smaller firms are still less able to handle new construction work.

The benefit of a free exchange of information in the petroleum industry

In the field of oil refining the engineering contractors enjoy the benefits of a relatively free exchange of information. Patents are generally pooled, particularly those relating to the important new chemical engineering technique of fluid or moving bed catalyst. As a result of this free availability of information, the customer no longer hesitates to ask the contractor to supply the engineering for a process which he has not developed himself.

The different situation in the chemical industry

In the field of chemical manufacture the situation is different. Here the secrets of new processes and process improvements are usually jealously guarded, and the manufacturer is often reluctant to disclose the necessary information even to a contractor. The projects are usually smaller and more easily handled by the engineering staff of the manufacturer. Expansion in smaller stages also makes it possible to keep the engineering staff continuously occupied. The activities of the contractors have therefore in the past largely been limited to such projects as boiler plants, fractionating equipment, Dowtherm heating systems, ammonia absorbers etc. and to processes like solvent extraction and refining of animal and vegetable oils, fatty acid distillation, nitrogen fixation and the manufacture of phthalic anhydride. These processes resemble those of the oil industry in that they are used by many firms and that experience gained from one installation can be utilised in the design of subsequent plants.

It is characteristic that two of the largest contractors visited reported that 80 % to 90 % of their respective activities are concerned with the oil industry and only 10 % to 20 % with the chemical industry. There is, however, a tendency for the projects in the chemical industry to become larger and more complex and therefore to have greater need of the services of the chemical engineering contractors. All the firms visited displayed considerable interest in a further expansion of their activities in the chemical field and examples can already be quoted of customers supplying the contractor with secret process information for the design of a plant not intended to be duplicated elsewhere.

The situation in Europe

In Europe there are a number of firms operating as chemical engineering contractors on a considerable scale. They specialise in plants for such purposes as the manufacture of sulphuric acid and cement, the refining of vegetable and animal oils and fats, the electrolytic production of hydrogen, chlorine and caustic soda, the production of explosives, a number of processes involving distillation, extraction and evaporation, and a variety of heat transfer operations.

There are, on the other hand, very few firms capable of undertaking the design and construction of oil refineries, and most of that work in Europe is done by American firms and their subsidiaries. It is undoubtedly the United States which has the widest knowledge of the many aspects of modern oil refining and it would seem to be to the great advantage of the European oil industry to have access to this know-how through the American contractors.

As stated previously, the position seems to be different in the chemical industry because in this field the firms of contractors generally do not know the processes and are able only to supply the engineering. Because the processes differ widely, they can have no specialised knowledge of the particular plants, and must rely entirely on their general

experience and highly developed organisation. In this general field of chemical industry there should be scope for European firms of contractors and there are already — as mentioned — such firms in existence.

It is of particular interest to note that in three of the smallest countries of Europe there are small, highly specialised firms working successfully for the world market in electrolytic cells, cement furnaces and large electric furnaces for carbide etc.

The Du Pont Company and other large manufacturing firms in the United States carry out the same type of development and design work as the large firms of chemical engineering contractors, and in that respect the situation is similar in Europe.

Organisation

General organisation

The large firms of chemical engineering contractors visited by the Mission each employ some 600 - 1,200 persons in their design establishments. The proportion of technical staff to non-technical was not generally ascertained, but one of the largest firms reported that their staff consisted of about 45 % engineers, 35 % draftsmen and 20 % buyers and clerks.

The organisation charts of two such firms are given in Annexes 3 and 4 to this Report.

Emphasis on process engineering

It is a characteristic feature of the organisation of these firms that they maintain separate departments for process design and for equipment design. The distinction between these functions has been defined in the chapter on the chemical engineer. One of the firms visited employs about 50 fully qualified chemical engineers in its process department.

The process information required for the mechanical design of the equipment includes the material and energy balances, the heat requirements, the sizes of the main plant components such as reactors, distillation columns, absorption towers etc. This information is usually assembled in a bound volume which is handed over to the equipment design department.

The process department is usually also responsible for the development of general data for process design. On the average, some 3 or 4 chemical engineers in each firm are allotted the task of extending and keeping up to date the process design data-books which contain in handy form the general design data necessary for the work of the department. These data-books, which run into several large volumes, are among the most treasured assets of these firms, and their importance can hardly be over-emphasised.

Internal specialisation

The organisation charts of these firms reveal a high degree of internal specialisation. As the organisation expands, it becomes possible to

establish separate sections for dealing with such items as vessels, heat exchangers, pumps, compressors, motors, instruments, automatic control etc. Through a number of similar assignments of limited scope the engineer gains extensive experience within his limited field and develops the ability to turn out a first-class job in the shortest possible time. This internal specialisation provides one of the main reasons for the high efficiency of these firms.

The possible dangers of excessive specialisation to the individual chemical engineer and the means of eliminating them have been dealt with in the previous chapter.

The project or job engineer

The high degree of internal specialisation in these firms necessitates special provision for the co-ordination of the numerous specialists. Each specialist is assigned one small section of each project but he can have little or no knowledge of how his work fits into the whole project, or of when his part of the work must be completed in order to enable his firm to finish the plant within the time-limit set by the contract.

It is clearly essential to assign one man to each large project or to a few small one. This job engineer, as he is called, takes over when the contract has been signed, although he has usually been called in already in the initial stages of negotiations. He has no direct influence on the working out of the process or the mechanical design, but he acts as an adviser and is responsible for ensuring that the contract is fulfilled and that the wishes of the customer are duly recognised by the designers. His main responsibility seems to be to see that the project is completed within the time-limit set by the contract. Very early in the work he must prepare schedules fixing time-limits for every section of the job. He must make sure that all information is available when required e.g. by the drawing office. In collaboration with the purchasing department he must make sure that the items with the longest delivery period are designed and ordered first. He must also, as soon as possible, get detailed plans and other information from the outside suppliers to enable layout and pipe drawings to be completed.

The job engineer is not directly concerned with the erection and starting up of the plant but he still represents the customer and must see that these operations are carried out in the manner most acceptable to him. He is also expected to write a " trouble report " which brings to the attention of the engineering department any difficulties experienced during the starting up and operation of the plant.

The large firms have a separate job engineers section under a chief job engineer.

The recruitment of job engineers is a difficult problem. The job engineer must have lengthy experience of all the different aspects of the work, and must be particularly well acquainted with the operation of plants. A high degree of specialisation is not conducive to the development of this type of man, and many job engineers are recruited from

manufacturing firms where they have been able to get the necessary operating experience. Some of the contracting firms move the more promising of their chemical engineers from one field to another with the object of giving them the widest possible experience and thus qualifying them for the important position of job engineer

Extensive use of highly qualified technical personnel

The high proportion of fully qualified engineers to draftsmen and clerks has already been stressed. Figures showing the proportion of chemical to mechanical engineers are not available, but generally it appears that the process departments are staffed entirely by chemical engineers while the project engineering departments are equally divided between chemical engineers and mechanical engineers. The equipment specialists are mostly mechanical engineers.

High qualifications are universally required; for chemical engineers the M.Sc. is usual and the Ph.D. is considered highly desirable. The cream of the young chemical engineers go into development and design work, whereas the less qualified are engaged in plant operation and other activities where the assignments are less exacting.

For the mechanical engineer the Ph.D. is not considered to be of great advantage, but the M.Sc. is desirable.

Incentives

There is a financial incentive for technical staff in that every rise in wages or salary is dependent on the quality of the work done. Promotion to a better position is also according to merit, never according to age or seniority. Inventions made by members of the staff are always rewarded. Whenever possible, members of the company's own staff are promoted to the higher positions in preference to recruiting from outside the organisation. In spite of the keen competition an excellent team spirit appears to exist among the members of the staff; there is sporting rather than cut- throat competition.

External specialisation

Extent of external specialisation

Specialisation and collaboration are not limited to the internal organisation of these firms but govern also their external relations. Most American firms seem quite content to sub-contract a considerable proportion of their work, provided they are convinced that the sub-contractor can do a better and cheaper job than they can do themselves. The condition that the job must be better and cheaper is rigidly observed, and a firm would not hesitate to change from an old reliable supplier to a newcomer if the latter could offer substantial advantages.

Even the largest chemical engineering contractor handling projects costing $ 200 million a year would not contemplate designing his own

pumps, filters, centrifuges, instruments etc. Such items are left to highly specialised and competent firms, on whom the main contractor can usually rely to provide the most suitable equipment for any requirement. It is often only necessary to specify the use of the equipment and the nature of the material to be handled. If it is not immediately obvious that the equipment will be suitable, the supplier will suggest carrying out the necessary tests in his well-equipped pilot plant laboratory, and if his equipment fails, he will often offer to design new models.

Examples of collaboration

An example of such collaboration is the development of the bucket elevator for the Thermophore catalytic cracking process. This elevator is required to handle 175 tons/h of catalyst at a temperature of 510°C (950°F) continuously for months without repair. This exceedingly difficult problem was solved technically by collaboration between the main contractor and a specialist in bucket elevators.

The corrosion service operated by several manufacturers of corrosion-resistant alloys provides another example. Suitable standard test specimens are supplied and an expert opinion is given on the result of this exposure to corrosive conditions. In spite of having corrosion experts of their own, the contracting firms make extensive use of this service.

Advantages of specialisation

There can be no doubt that the reliable and extensive services of the equipment suppliers greatly simplify and expedite development and design work. With the knowledge that satisfactory filters, pumps, instruments etc. can be purchased, the development and design engineers can concentrate their attention on such vital and difficult problems as reactors, fractionating equipment, absorption systems, etc.

There is little or no danger that the equipment manufacturer will try to sell his equipment for applications for which it is not suitable. The pressure of competition makes it a matter of life and death for him to maintain his reputation for reliability rather than to attempt to effect a short-lived increase in the volume of his sales. The large firms of chemical engineering contractors are in a particularly strong position, since their sub-contractors are relatively small and can ill afford the loss of such important customers.

In the application of the principle of specialisation, Europe undoubtedly lags behind the United States. This can be attributed to many causes, most of which are outside the control of the European industry; but it would appear that efficiency could be considerably increased if more European managements were prepared to make greater use of sub-contractors whenever these could produce better and cheaper than their own units.

Standardisation

Standardisation in general is discussed in some detail in a separate chapter, and this chapter will be limited to a summary of the important aspects of this wide subject.

Company standardisation

The American chemical engineering contractors as well as the equipment manufacturers are fully conscious of the benefits to be derived from extensive standardisation in the managerial as well as in the technical field. These firms are sufficiently large to develop their own standards, and they have created the necessary organisation for doing so. Company standardisation is universally accepted in the United States as a means of increasing efficiency, and it is undoubtedly applied to a greater extent than in Europe

Industry-wide and national standardisation

These firms also take an active part in the work carried out by professional bodies and trade associations to create industry-wide and national standards but the organisational machinery is very complex and progress is slow. Industry-wide or national standards are, however, always used whenever applicable.

Several of the firms visited were concerned about the dangers of overstandardisation, particularly in the chemical industry. Chemical equipment often has to be specially made and excessive standardisation might reduce flexibility and hamper progress. For these reasons they keep a close watch on the activities of the professional bodies and trade associations in this field.

Simplification

Simplification is no less important than specialisation and standardisation. The principle of simplification has been applied with conspicuous success in the mass production industries of the United States, but in the chemical industry it has also contributed substantially to the lowering of costs.

The principle involves a reduction of the number of components and, wherever possible, of the number of types of equipment offered by the manufacturer. These two aims can easily be pursued independently. It was reported that by redesigning a range of electric motors with the emphasis on standardisation and simplification the number of component parts was in one case reduced from 331 to 176 without limiting the customer's legitimate choice.

The application of the principle of simplification to the production of chemical equipment is discussed in the chapter on miscellaneous equipment for the chemical industry. It will suffice here to point out that in the United States this industry has adopted simplification as a

matter of policy. It must not, however, be forgotten that the requirements of chemical processing are diverse, and that specially designed equipment in many cases provides the most economical solution.

There can be little doubt that the principle of simplification is more widely accepted by the equipment manufacturers in the United States than in Europe, and that the European industries have much to gain by making a determined effort to simplify both procedures and products.

Pilot plant work

When to carry out pilot plant work

The importance of pilot plant work was recognised by all the firms visited. But they pointed out that this stage of development work is very costly and that in some cases the pilot plant work costs as much as the final commercial plant. The work also takes a long time, and unless carefully planned, will not furnish the information required. Before undertaking pilot plant work two conditions should therefore be fulfilled : firstly, as much information as possible should have been obtained from laboratory work, which is incomparably cheaper ; secondly, an extensive economic analysis of the project should have given a favourable result. At this stage too, it is necessary to have an approximate idea of the size of the commercial plant in order to keep the expenses on the pilot plant within economically justified limits.

If the necessary process information can be purchased, this will in practically all cases prove more economical than pilot plant work.

In some cases the main purpose of the pilot plant is to provide enough of the product to test its sales possibilities.

The place of the pilot plant in the development and commercialisation of a new process or project is shown in Annex V to this Report.

Pilot plant work in the petroleum and chemical industries

There are several important differences between pilot plant work in the chemical and in the petroleum industries. Since chemical plants are generally much smaller than oil refineries, the amount of money invested in chemical pilot plants must necessarily be much smaller. Furthermore, in the petroleum industry several commercial plants are usually built on the basis of work carried out in a single pilot plant, whereas often in the chemical industry only a single unit is built. The firms visited consider that in the chemical industry it may often be economically sound to invest less in pilot plant work and instead to be prepared to make a few alterations to the commercial plant as a result of experience gained during the starting-up period. It must, however, be recognised that the difficulties involved in the scaling-up of a chemical plant are in many cases greater than for an oil refinery ; the handling of solids and residues often presents greater problems. Owing to the greater complexity of the processes employed in the chemical industry, it is often necessary to build a faithful replica of the full-scale plant,

whereas in the petroleum industry it is generally sufficient to carry out the basic operations and test the products obtained.

For these reasons development in the chemical industry by pilot plant work is generally more difficult and relatively more expensive than in the petroleum industry. It is most important to consider every case on its own merits.

The size of the pilot plant

For economic reasons the pilot plant should be kept to the minimum compatible with the aim of simulating the flow pattern of the full-scale plant and obtaining representative and consistent data. It was stated that in the oil industry the ratio of the full-scale to the pilot plant is usually between 2,000 : 1 and 5,000 : 1. The ratio depends on the type of equipment intended for the commercial unit.

The pilot plant must not be so small as to create difficulty in controlling the flow of materials. Considerable progress has been made recently in this field and automatic control of liquid streams down to about 0.2 litre per hour is now considered feasible, even if the pressure is of the order of 100 kg/cm^2. Continuous feed of solid materials at a controlled rate is much more difficult.

In many cases handling losses are of importance and determine the minimum size of the pilot plant.

Pilot plant design

The considerations governing the design of pilot plants are very different from those applying to the commercial plant. Since the optimum conditions are not known, the design must be sufficiently flexible to permit the operating conditions to be altered in the ratio of about 10:1. In many cases it is necessary to prepare in advance several alternative designs to make allowance for possible alterations. Ample instrumentation should be provided to enable adequate data to be collected.

It is important that the design should be as simple as possible. Whenever feasible such operations as distillation and purification should be carried out outside the pilot plant. Mechanical equipment which might cause difficulties should be avoided, as it is best tried out separately and not as a part of the pilot plant. Heat transfer coefficients can in most cases be calculated from theory or estimated from practical experience, and it is not generally the purpose of the pilot plant to determine such data. Heating and cooling surfaces should therefore be very generous to allow the greatest possible flexibility. Economies obtained by heat recuperation are unimportant on the pilot scale.

In continuous plants the quantity of material in the course of processing must be as small as possible in order to reduce the time required to reach stationary conditions.

Special difficulties are encountered in the design of pilot plant reac-

tors, particularly of the vapour phase catalytic type. It is impossible to duplicate the full-scale unit except on the full scale, and some compromise is unavoidable. It is clearly impossible to retain geometric similarity, space velocity, linear velocity and volume to surface ratio on the two scales. The different temperature gradients are particularly troublesome, and excessive heat losses in the pilot plant must be offset by means of electric heaters — and in extreme cases additional thermal insulation — placed inside the reactors.

Pilot plant construction

The equipment should preferably be of standard design and purchased from the equipment specialists.

To avoid loss of material through leaky joints, pipes should generally be welded but sufficient joints should be retained to allow dismantling for cleaning, repairs and alterations.

Pilot plant operation

Pilot plants should be operated in such a way that the observations made provide reliable information on the following points :

Material and energy balances.

Reaction rates.

Optimum operating conditions.

Economics of process.

While the experimental work is proceeding, economic analyses and commercial estimates must be made to ensure that the work is taking the line most likely to lead to commercial applications. By this means the fact that a project has little chance of commercial success can be detected at an early stage and expenditure on it curtailed.

The time factor is of the utmost importance in development work. For that reason pilot plant laboratories should be equipped with ample workshop facilities in order to enable inevitable alterations to be carried out with the least possible delay.

Trends to eliminate pilot plant work

The modern tendency to reduce or even eliminate pilot plant work was discussed by only one of the firms visited by the Mission. Most of the other firms strongly stressed the necessity of going through the pilot plant stage.

The need for a pilot plant arises largely because ignorance of reaction kinetics and of the flow pattern makes it impossible to scale up the process with any certainty. On the other hand, the chemical reactions involved, including side reaction, can be exhaustively examined in the laboratory.

Research in applied chemical kinetics is at present proceeding in many laboratories throughout the world, and particularly in the United States. The object of this work is to develop methods of establishing on the laboratory scale the kinetics of catalytic reactions in particular

and of combining this knowledge with the knowledge of heat transfer and fluid flow in the design of the full-scale reactor. The heavy expenditure of money and time on development work could then be drastically reduced.

These new tools are not yet ready for general use in industry, but they have been tried with great success on a few selected occasions in the oil industry in the United States. Atomic energy development offers examples of full-scale plants designed directly on the basis of information obtained in the laboratory with quantities of material too small to be seen with the naked eye and in some cases even too small to be weighed with the most sensitive analytical balance.

There can be little doubt that the number of plants designed without pilot plant information will increase rapidly in the future. In view of this the European chemical industry would be well advised to attach special significance to these new developments in applied chemical kinetics. A firm which is able to start up a full-scale plant while his competitor is starting up a pilot plant secures an advantage which might prove decisive.

Conclusions

1. The large firms of chemical engineering contractors have contributed greatly to the rapid expansion of the petroleum and petrochemical industries by :

   a) Providing design engineering services which the individual refiner cannot economically maintain himself.

   b) Laying emphasis on the engineering aspects of the development of new processes.

2. The high efficiency of these firms is mainly due to :

   a) The employment of a large number of highly qualified chemical engineers.

   b) The adoption as a matter of policy of the principles of internal specialisation, standardisation and simplification.

   c) The provision of co-ordination through job engineers.

   d) Advanced personnel management with incentive schemes.

   e) The policy of assigning staff to the task of collecting relevant technical information and making it readily available to the designers.

   f) The policy of extensive sub-contracting.

   g) The excellent services provided by the specialised suppliers of equipment.

3. The extensive pooling of patents and the publication of general chemical engineering information in the petroleum industry has greatly aided progress.

European firms are recommended to consider the possibility of applying these principles in their own individual cases.

III

STANDARDISATION

Introduction

Standardisation in all its aspects is generally recognised to have contributed very considerably to the efficiency of industry in the United States, as in other countries where it has been applied. There is little doubt that standardisation in the broad sense has been applied to a much greater extent in the United States than in Europe. The rapid growth of the mass production industries in the United States and their high productivity has only been made possible by the introduction of a high degree of standardisation in its several aspects.

Types of standardisation

The various types of standardisation fall under two main headings, which in the United States are referred to as " technical " and " managerial ". The managerial standards, as defined by one company, are concerned with organisation practices, worker performance, accounting systems, personnel procedures, distribution methods, and other activities not directly connected with any products or processes of manufacture. It is not proposed to discuss this type of standard, but it should be noted that considerable value is attached to managerial standards by large companies which have spent considerable effort on developing and applying them.

Technical standards can be divided into the following groups :

1 Dimensional
2 Performance.
3. Test methods.
4. Safety.
5. Definitions and symbols.

The interest of the Mission was primarily in dimensional standardisation as a means of reducing initial and running costs of chemical plant.

Standardisation is also classified according to the level at which

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it is practised, e.g. within a company, within an industry, at national or international level. It is particularly important, when considering standardisation in the United States, to appreciate the extent to which it is practised on a company basis; a large proportion of the standards produced ultimately for wider use arise from the expansion of company practices. In fact, one of the main sources of work on dimensional standardisation is the considerable effort made by many individual companies to draw up and apply standard specifications to facilitate their own operations.

Organisation

Standardisation demands an organisation which can permit and encourage discussion of proposed standards among those interested with a view to their subsequent production, endorsement and publication. Such an organisation must exist in some form or other, however informal, whether the work is proceeding on a company or a national basis.

In each country in Europe there is one organisation which is responsible for dimensional standardisation, and it is generally supported at least in part by the State. In the United States there is also nominally one body which is ultimately responsible for the production of national standards, namely the American Standards Association. In practice, however, there are a great number of bodies which produce standards on an industry basis and the standards produced are widely used and accepted. One particularly important body is the American Society for Testing Materials, which has already published about 2,000 standards. The American Petroleum Institute is another body which is very active in the production of standards which are used not only in America, but also in the petroleum industry throughout the world.

In addition, nearly all large companies produce their own standards to supplement national and industry standards, on which they keep a very careful eye to ensure as far as possible that there is no conflict with their own requirements.

Company standardisation

The companies visited each possessed a very comprehensive book of standards which was carefully kept up to date. Whether or not these companies had a special department devoted to internal standardisation, there was no doubt that standardisation was being applied very enthusiastically. One chemical company's system is given as an example of the type of organisation set up.

Standardisation organisation in a chemical engineering company

The organisation deals with standards for products, purchasing, engineering and operating procedure. Only the work of the Technical

Standards Committee, which deals with purchasing and engineering specifications, will be described.

It is the definite policy of this company to produce engineering standards as the need for them develops, but at the same time to use industry or national standards whenever these are applicable.

The company is represented on approved organisations working for the establishment of certain national standards, with the object both of encouraging and helping the work and also ensuring that standardisation is not taken too far in any direction prematurely.

The Technical Standards Committee of the company is responsible for all the standards produced, whether they are applicable to one division or to the whole company. Each division can put forward standards in which it is principally interested in collaboration with other divisions as desirable. A proposal for a new standard is always carefully examined to ensure that the ground is not already covered by a national standard.

When a new standard is first produced it remains a " tentative standard " for a period of six months; if it proves valuable in practice, it is adopted as a " working standard " for future use, but if it proves unnecessary or unsuitable, it is dropped. Great care is always taken to ensure that standardisation does not act as a brake on development, and if any standard shows signs of doing so, it is dropped and replaced by a new one.

It is interesting to note that new engineering staff are very often attached to the standards section, as in this particular company, for a period of training. There are two reasons for this practice. The first is that the new man will be brought into contact with all the commonly used developments, and the second is that he will bring a fresh mind to the work and may see anomalies or inconsistencies which have crept in unnoticed during the course of time, while the standard was being evolved.

It is considered most important to keep the standards up to date.

Application of company standardisation

The main obstacle to increased standardisation in the chemical industry is the great variety of requirements, which in many cases makes it necessary to design the equipment specifically for each particular application. This difficulty can be reduced in two ways. The most generally applicable method is to limit standardisation to the individual components, national standards being almost exclusively used for such components as screw threads, pipe diameters and fittings etc.., and company standards for stagings, ladders, etc..

The other method of combining standardisation with flexibility is illustrated by the standardisation of glass-lined, agitated reaction vessels. In spite of the fact that such vessels are used for a great variety of purposes with widely differing requirements of agitation and heat

transfer, even the agitator is standardised. The different degree of agitation is obtained by altering the agitator speed and the position of a standardised, but adjustable, baffle. The physical dimensions are fixed in standard equipment and the necessary flexibility introduced by means of advanced design. This method is noteworthy and is undoubtedly capable of wider application.

It is important to note that internal standards of large companies are often used by other companies (both large and small) and in this way the benefits of company standardisation are spread, to the advantage of both customer and supplier.

Professional bodies and trade associations

A large number of professional bodies and trade associations publish their own standards. These organisations are also members of the American Standards Association, which correlates the work of its members at their request to produce common standards on a national basis.

The American Society for Testing Materials is probably the best known of these bodies. It was founded in 1902 and in 1946 had 6,000 members. New standard test methods and specifications, as well as the revision of existing ones, are continually being considered by the A.S.T.M. Standing Committees, on which user and maker are represented. These Committees also correlate the investigations carried out to establish the basis of new test methods and arrange for the examination of the information so obtained by the presentation of papers at A.S.T.M. meetings. They also arrange symposia on technical subjects with other engineering groups, and so fulfil a valuable function in education, as well as in research and standardisation.

Similarly, the well-known American Petroleum Institute is continually working to produce standards for all the materials, equipment and test methods commonly used in the oil-field and the refinery.

The American Standards Association

The A.S.A. was founded in 1918 and has grown rapidly until it now includes all the important professional bodies and trade associations, as well as some thousands of individual companies. Its main function is to correlate the work on standardisation which is proceeding in all these organisations, and it operates on a voluntary principle, as do corresponding organisations in Europe. It is the natural body to undertake negotiations with other countries on international standardisation and theoretically it is well placed to do this. It is easy to appreciate, however, that difficulties must arise in international negotiations of this sort, since A.S.A. must in general refer back to the particular bodies concerned when compromise proposals are under discussion.

It would seem that the main importance of A.S.A. lies in its influence towards a national pattern of standardisation.

Government agencies

The large volume of Federal purchases, based generally on national standards, has a very important influence and also tends to impose a national pattern on standardisation, since the equipment is supplied by a very large number of firms, both great and small, from all types of industry. Federal specifications are therefore likely to be used by other buyers.

Conclusions

In considering the general problem of standardisation in the United States, it is useful to compare it with Europe as a whole, with individual industries or large companies corresponding to the individual European countries, and the A.S.A. corresponding to the now reconstituted I.S.A., which was formerly responsible for international standardisation in Europe. The general pattern of the methods by which company, industry and national standards are produced in the United States is sufficiently clear, but the details of the relations between the various standardising bodies, individual companies, and the A.S.A. must be most complex. It is apparent that the large organisations in industry, as well as the government buying organisations, are sufficiently large to make internal standardisation economic from their own point of view and that of their suppliers. The latter are assisted by the tendency of other companies (not necessarily small) to order to the same specifications. It would seem that national standards are generally used if suitable, but that by far the greatest amount of standardisation is carried out in the individual organisations.

There seems to be little doubt that the machinery set up the national standards institutions in each country in Europe for the production of national standards is so much simpler that, if the value of standards was appreciated to the same extent, progress in Europe would be very much more rapid than it ever could be under the complex system in the United States. At the same time, as already pointed out, it is more appropriate to compare the production of United States standards with the production of international standards among European nations, and if this is done the difficulties in Europe at once become obvious. The logical conclusion is that the main lesson to be learnt from a study of standardisation in America is that industry as a whole and individual companies recognise the great value of standardisation and are very active and successful in applying it to meet their own needs. Therefore the chief need in this field in Europe at the present time is to make known the advantages to be gained and to create a demand for standardisation. This demand can easily be met by expanding the existing national organisations.

Recommendations

Further attempts should be made to draw the attention of the European chemical industry to the advantages to be gained from a wider application of standardisation.

The existing national standards organisations should be supported and encouraged in their work.

Ways and means of promoting international standardisation should be sought.

IV

GENERAL DISCUSSION OF THE WORKING METHODS OF THE CHEMICAL INDUSTRY IN THE UNITED STATES

The transfer of industrial leadership from Europe to America

There can be little doubt that the American chemical and allied industries today hold a leading position in the world in productivity as well as range and volume of output. This has not always been so. In 1916 these industries were insignificant in comparison with those of Europe, and in addition Europe had a well-established background of tradition and achievement in the fundamental sciences. In spite of these advantages in favour of the old world, in less than fifty years the American industry reached equality in the field of industrial chemistry and superiority in chemical engineering. It is vitally important for the European chemical industry to enquire into the reasons for this development, and if possible to devise means of competing on equal terms in future.

The nature of the problem

The shortcoming of Europe is certainly not due to any lack of brilliant chemists or physicists, not even in the field of applied science. The European origin of such comparatively new products as DDT, gammexane, polyethylene, plexiglass, antimalarial drugs, penicillin and acetylene derivatives provides ample evidence in support of this statement.

Many of the most important techniques which form the basis of the most advanced chemical and petroleum processing in the United States have long been known and practised in Europe on an industrial scale. As an example, azeotropic and extractive distillation have long been used for the manufacture of esters, absolute alcohol and concentrated nitric acid. The fluidised bed method was in part foreshadowed by the Winkler generator.

These examples of methods which originated in Europe, but received full development and commercial exploitation in the United States,

show that Europe does not lack individual brilliance. There does, however, seem to be less aptitude for organised and determined development work and for commercial exploitation.

The story of molecular distillation is particularly revealing in this respect. This technique was originally developed and applied industrially in Europe, but with very limited commercial success. It was subsequently taken up in the United States, and after years of very expensive engineering development it finally emerged in a satisfactory technical form. Intensive advertising persuaded the American public that their diet had to be supplemented by vitamin pills, and the commercial success of the undertaking was assured. American equipment for molecular distillation is now being installed in several European countries.

American success in organised research

The difference between the American and the European attitude towards research is illustrated by the development of antibiotics in general. The success of penicillin made it practically certain that other antibiotics of great medical and commercial value were awaiting discovery by anyone who cared to look sufficiently closely for them. This was realised in Europe as well as in the United States, but in Europe only scattered attempts were made to find these treasures. The great discovery of penicillin was made by an individual and a comparatively small group of individuals was responsible for extracting it and proving its therapeutic value. The large-scale organised research required in a systematic search for other antibiotic substances was largely the work of Americans.

The situation is similar in the case of less important products, such as Teflon and Kel-F. The polymerisation of ethylene was discovered and developed technically in Europe, but the polymerisation of halogenated ethylene was an American achievement.

Highly organised research has, of course, also been carried out in Europe with particular success in such fields as dyestuffs, pharmaceuticals, plastics and insecticides. These fields of research are similar in that they have been built up gradually. It appears that financial support for projects in such new fields as silicone chemistry and the search for antibiotics is more readily forthcoming in the United States than in Europe.

Little improvement in sight

The European chemical industry is undoubtedly beginning to realise the importance of organised research, particularly in chemical engineering, but there is little reason to believe that the target is much beyond the present American position.

The intensive scientific and engineering studies which are being pressed forward with great favour in the United States in such fields as advanced acetylene chemistry and high pressure addition reactions

with carbon monoxide make it almost inevitable that these European achievements will also find their full technical and commercial exploitation at the hands of the Americans. The astonishing interest displayed by American industrial leaders in a compound such as cyclooctatetraene shows that the European industry will have to look far ahead if it is ever to catch up with the American.

Conditions beyond the control of industry and favourable to the United States

Large home market with free competition

Certain favourable conditions have given the United States a considerable advantage. The large home market promises an attractive financial reward for investment in successful new development. A firm starting a new line of research or development can be reasonably certain of an opportunity to exploit a possible success. Its only anxiety will be that its competitors may reply with still better products or more efficient processes. In Europe, on the other hand, the inventor knows that as soon as his production is successfully established in his own country, factories will soon be built elsewhere, with or without his consent, according to the patent laws of the countries concerned. His only consolation is that when his own process ultimately becomes obsolete he can himself shelter behind his country's tariff walls and carry on peacefully with his then less efficient methods. Free competition acts as a spur to efficiency not only because it enables a company to benefit commercially from improvements and inventions, but also because loss of business would be the inevitable result of stagnation and inability to keep ahead in the race for progress. The vice-president of one of the largest firms of chemical engineering contractors visited by the Mission openly stated that they had only about 50-100 possible customers and that there were 5 large and 20-30 small firms all competing for them. Poor design, high prices and inefficiency would soon put them out of business. Reputation is the most jealously guarded asset of these firms.

The large American market is moreover a pre-requisite for that high degree of specialisation which is an important feature of the American industrial organisation. The larger the market, the greater the need for the specialist, and the more specialists the greater the efficiency of the industrial community as a whole.

The effect of two world wars

The Americans have also enjoyed the advantage of being outside the theatre of two major wars which cost European industry very dear. In Europe war acted as a brake on the development of the chemical industries whereas it considerably accelerated expansion in the United States. As an example of the effect of the last war on industrial development, it may be mentioned that atomic energy and penicillin, which

both originated in Europe, had to be developed largely in the United States because of the strain of war on European industries.

Superior natural resources

The natural resources of the United States are undoubtedly greater and more accessible than those of Europe. This is particularly true for oil and natural gas, but also for sulphur, phosphate rock etc. The leading industrial countries of Europe have practically no deposits of these essential raw materials. Seen from this point of view it is perhaps not difficult to explain why the petroleum and petrochemical industries were developed in the United States, while the European countries, poor in oil, devoted their energy to such processes as coal hydrogenation, Fischer-Tropsch synthesis and acetylene and alcohol chemistry.

The American progressive attitude and talent for organisation and exploitation

The favourable conditions of a large market, greater natural resources and a location outside the theatre of two major wars do not alone explain the rapid progress made by the chemical industry in the United States. In addition there is the progressive attitude of the people and their talent for developing and applying the result of research work to large-scale operation.

This does not mean that American business men invest their money recklessly in anything that is new. On the contrary, they subject any proposal to a searching analysis of commercial prospects, and, if promising, they apply their highly developed and efficient technique to translating the laboratory results into full-scale production and commercial success with the minimum delay.

It is important to analyse this attitude and to study the means by which the United States preserves and encourages it.

The first point to notice is that a would-be inventor can be assured that managements will not hesitate to try out his ideas and adopt them as soon as they have proved their value. This is a powerful incentive to invention and development. The interval between the act of invention and the reaping of the reward is shorter in the United States than in Europe. This applies to individuals as well as to manufacturers of equipment, instruments, materials of construction, etc.

We shall now consider various instances of this American capacities for exploitation.

Organisation on a " specialist " basis

Of central importance is the American talent for organisation. Even the most complex task is broken down into well-defined and carefully studied elements which are subsequently joined together in the final achievement. When the breakdown has been taken far enough, the elements of even the most complex enterprise become sufficiently simple

to be mastered by well trained, but otherwise quite ordinary people. This is the secret of mass production which is so organised that even such complex products as aero engines can be built by persons who would mostly be unable to explain how the finished engine works. Europe is attempting to follow this system, but to a smaller extent.

Efficient organisation is characterised by the systematic adoption of the principles of specialisation, with co-ordination, standardisation and simplification. In the United States the manufacture of chemical and petroleum products is organised on a " specialist " basis to a degree unknown in Europe. This applies to the internal organisation of the individual firms as well as to the structure of the industries as a whole, including contractors, equipment manufacturers, transport agents, etc.

Application of the production line technique to design and development work

In the United States the technique of mass production has been adapted to engineering design. The vice-president of one of the large firms of chemical engineering contractors described his engineering organisation as a production line with each project passing through the hands of more than 50 people. By applying the principle of specialisation and co-ordination the human material available is utilised to the best advantage. In this direction greater progress has been made in the United States than in Europe.

This technique is also applied with great advantage to development work and in some cases even to research work. It is essential to realise that the nature of invention is changing slowly but significantly. Most of the important recent developments in the chemical industry in the United States cannot be traced back to any particular individual; they are the result of the co-operative efforts of many. Europe has contributed much of the individual brilliance, America much of the organised co-operation.

The production line technique is much in evidence in pilot plant work. The process developed in the laboratory is tentatively transposed to full scale for a preliminary estimate of investment and operating costs. The project is scrutinised from the point of view of sales prospects, and the decision to build the pilot plant reached. The physical chemist provides the necessary equilibrium data, while the process and equipment for the pilot plant are designed mainly by the chemical engineer. After erection it is run by the chemical engineer, with the co-operation of the analytical and research chemists and the mechanical engineer, while the commercial prospects are constantly under review. Efficient pilot plant work thus requires the co-operation of many specialists among whom information is constantly passing, with each individual making his contribution, large or small.

Specialisation on a national basis

The most striking example of specialisation on a national basis in the chemical and petroleum industries is the extensive use of chemical

engineering contractors for the design and construction of new plant.

Moreover, there are at the service of the chemical engineering contractors and of the chemical industry in general a number of highly specialised equipment manufacturers to deal with such items as pumps, compressors, filters, centrifuges, driers, agitators, extractors, evaporators, storage tanks, etc.

Another example of the specialist services offered in the United States is the leasing of railcars for a variety of purposes.

The services offered by the instrument makers who specialise to some extent on some field of instrumentation and automatic control are particularly important. These firms are very quick to fill the rapidly expanding needs of the chemical industry and in many cases to anticipate future needs. Many of the new processes and techniques developed in the United States require elaborate and advanced instrumental aid and could perhaps not have been developed without the co-operation of the instrument makers.

External specialisation has, of course, also developed in Europe where there are firms of chemical engineering contractors, equipment and instrument specialists. Some of these firms are quite large, and work for the world market in certain special types of equipment, competing effectively in the United States. Nevertheless, specialisation appears to be less advanced in Europe than in the United States and the attitude of industry in the two continents seems to be rather different.

During its visits to some twenty firms engaged in oil refining, chemical engineering contracting, transport and the manufacture of equipment, instruments and materials of construction, the Mission did not meet any staff who showed any inclination to boast that their firm was self-sufficient. On the contrary, they were anxious to point out how their firms provided an efficient link in the American chemical industry.

The willingness to use subcontractors appeared to be universal, and the question of whether or not to subcontract seemed to be decided entirely on grounds of cost, never on such irrational grounds as prestige. The sub-contractors and suppliers are forced to keep up with new developments because under a highly competitive system they would be dropped as soon as their costs ceased to be the lowest.

The difference between the American and the European attitude towards specialisation can perhaps best be summed up by saying that the importance of not doing anything that others can do better is more widely understood in the new world than in the old.

Standardisation

Standardisation of a product is recognised as one of the most important factors for decreasing production costs and the suppliers of equipment adopt it as a means of supplying what is needed at the lowest price. Standardisation in the United States is a characteristic of the internal organisation of the individual firms rather than of the

aspect of industry as a whole. The different aspects of standardisation have been discussed in some detail in a separate chapter, and will not be dealt with further here.

The guiding principle : will it pay?

It is in the nature of business that managements everywhere in the world choose their research and development projects according to their economic importance, rather than their scientific interest. Science must necessarily be regarded only as a means to an end. It is, however, apparent that the relationship between economics on the one side, and chemical and engineering development and research on the other is closer in America than elsewhere, and more of a routine nature. The stress on economics certainly does not exclude long-term research and development, but it does imply that even such projects must be subjected to frequent commercial assessment.

It is of great interest to note that this attitude is also engrained in the minds of many academic workers and teachers, particularly in the field of chemical engineering. In the universities, institutes of technology and other research organisations in the United States there are many outstanding workers who are willing to compromise and combine strict scientific principles with empirical methods in order to deal with the complex problems of interest to industry. The academic worker always finds it a very strong temptation to select problems and systems which are sufficiently simple to be amenable to rigourous scientific analysis. It is difficult to over-estimate the importance to the American chemical industry of the work carried out in the Universities and other institutions with the primary object of providing the tools which industry requires for handling its complex problems.

Industry is well aware of the importance of this work and provides generous financial support. Another essential factor is that these research workers are recognised and enjoy a high professional status in the United States. The result is that most of the significant data which constitute the working tools of the modern chemical engineer have been provided by the new world rather than by the old.

To take an example, the principle of corresponding states has proved to be practically indispensable in handling the complex phase-relationships of the petroleum industry. This principle was formulated in Europe many years ago, but was considered by most scientists to be of doubtful scientific value and consequently of little or no interest.

In this connection, the new developments in applied chemical kinetics are also of interest. Apparent reaction mechanisms are used successfully for reactor design, although they are not believed to give a correct scientific picture of the reaction.

The occurrences in a packed tower are too complex to be treated exhaustively on the sole basis of the laws of hydrodynamics, diffusion and heat conduction, and they are therefore of little or no interest to

the pure scientist. A very large amount of semi-empirical work has, however, been carried out in this field which is of capital importance to industry and the American contribution is by far the most important. The same applies to problems such as the hydraulic gradient on bubble-trays for fractionating columns.

Exchange of information

In the United States as in Europe commercial success depends to a certain extent on keeping the secrets of trade and manufacturing technique. Many inventions cannot be properly protected by patents, and secrecy must be observed in order to secure a return on the money invested in research and development.

A notable exception to this general rule is the United States oil industry. As mentioned previously, this industry has agreed to pool patents and processes. This arrangement was originally introduced to solve the difficulties arising from the fact that so many different firms held patents relating to various aspects of the new moving bed and fluidising techniques that the design of efficient plants in this field became almost impossible for any one firm. This free availability of patents and process information made it possible for the chemical engineering contractors to operate successfully in the petroleum industry. There can be little doubt that this policy has contributed considerably to the efficiency and rapid expansion of the oil industry in the United States.

Although it is part of the general policy of the chemical industry in the United States as well as in Europe to keep processes and techniques secret there appears to be an important difference in attitude. American managements generally show greater willingness to distinguish between information which must be kept secret and that which need not. They are generally anxious that their firms should make a contribution to the general pool of knowledge, and they realise that their reputation to some extent depends on it. The publication of good papers has a considerable advertisement value for the firm, and the opportunity to present papers occasionally makes it easier to attract first-class chemists and chemical engineers who may wish to establish a reputation outside the firms where they are employed. This policy has long been adopted by some of the most progressive European firms, but the great majority still maintain indiscriminate secrecy.

For various reasons, such as the " specialist " basis of working and the higher staff turnover, there appears to be a wider circulation of technical information in the United States than in Europe. If a firm is developing something entirely new in the way of plant or process it may be possible to keep the important details secret, but it will usually soon become known that a development of that kind is being carried out. The result of the fairly rapid diffusion of information in the United States is that a development in one field is quickly applied to other fields.

Advanced methods of training and personnel management

The complex machinery of the United States chemical industry can operate efficiently only if it is manned by well-trained technicians able to carry out the many specialist functions and provide the necessary co-ordination. The most important is the chemical engineer, whose training was dealt with in some detail in a previous chapter. It will suffice here to recall that university training is broad and quantitative rather than descriptive. Specialist training is provided largely by industry.

PART II

V

PROCESS INSTRUMENTATION

Introduction

Definition of process instrumentation

The term process instrumentation embraces all measuring, recording and controlling equipment used in the operation of plants in the process industries, including ancillary equipment and provision of the necessary services. It also covers the method of installing such equipment and the technique of applying it to the best advantage to facilitate plant control and accountancy and to ensure the optimum plant efficiency in terms of the cost and quality of the final product.

The extent of discussions on instrumentation

The Mission as a whole was given an opportunity of visiting two instrument makers and one member visited three other makers. Instrumentation was also discussed with the staff of the major chemical engineering contractors and of the other engineering companies visited. A profitable day was also spent by the whole Mission in a large oil refinery which possessed some very progressively instrumented plant.

These visits and discussions showed quite conclusively that industry in general attaches great importance to instrumentation. They also showed the present trends in development and the reasons for them. There was not, however, an opportunity of studying application practice in the chemical industry itself, nor to discover the views of the user in the chemical industry at first hand.

Main purpose of this chapter

The present purpose is to discuss the reasons which it is thought explain the high level of instrumentation in the United States, and to emphasise the logical conclusions to which they lead. Of these conclusions, the most important is that instrumentation is regarded as vital to high productivity by American industry as a whole. It can therefore

be expected that European industrial productivity could also be materially increased by employing instrumentation to a similar extent.

The first problem is therefore to convince those responsible in industry that this is so. The second is to do everything possible to ensure that the increased demand for equipment can be met. The first problem is not only the most difficult but also the most urgent.

Data on savings obtainable by instrumentation

There is a fundamental weakness in this chapter because no firm data are presented on the actual savings which can be expected from employing instrumentation fully in chemical plants. Data of significance to the chemical industry must necessarily be obtained from users of instrumentation in the chemical industry, and, more particularly, such data can only be used with reference to similar plants and processes. The opportunity of collecting reliable data from the chemical industry did not arise. No attempt has been made to estimate a representative percentage saving of plant costs due to instrumentation because generalisations are almost impossible to make in this respect. They are generally meaningless and can be most misleading.

It is recommended that those responsible for increasing the productivity of chemicals plants should make an assessment of the savings which might be effected by improved instrumentation. Such assessments are made as a regular procedure in may United States factories. The data obtained is considered to be very valuable and many examples of their use to obtain increased efficiency were quoted, e.g. improved quality of product, lower percentage of reject product, time saved by decreasing shutdown periods, fuel economy, and savings both on the maintenance of plant and the instruments themselves.

It cannot be too strongly stressed that, whatever the position is in other industries, the object of applying full instrumentation and automatic control in the chemical industry is not to save manpower, but to achieve better results than are possible over long periods by manual control.

The greatest economic justification for automatic control is therefore found in complex plants where a large number of variables have to be controlled and correlated in order to ensure continuous and smooth operation. The complexity and precision of control required on chemical plants is increasing rapidly and in the future there must be an increase in the number of plants which cannot be operated economically without comprehensive and properly integrated automatic control systems.

At the same time the economies to be effected on existing and far less complex plants by the use of instrumentation and control should not be overlooked.

Detailed technical information

It was not possible to spend sufficient time on the study of instrumentation to obtain any considerable amount of detailed information.

The purpose of the Mission was to obtain a broad impression of current procedure and ideas in each of the specialised subjects comprised in chemical engineering. It is not proposed therefore to attempt to describe in the body of the report either the standard, well-established equipment which is available in the United States, or the new designs in course of development. The well-established equipment is already well-known in Europe and its application to chemical plant control is discussed in many papers published in the technical journals. Indeed much of this equipment has for many years been manufactured in Europe under licence and it has been widely used by many companies alongside equipment designed in Europe itself.

At the same time it is thought that the brief notes and the illustrations given in Annex VI may be interesting to the reader who is not a specialist in instrumentation. The Annex is intended to illustrate the general trends observed and to indicate a few current designs.

The relative general levels of instrumentation in the United States and in Europe

There can be no doubt that the general level of instrumentation in the United States is considerably higher than in Europe. Neither can there be any doubt that the very much higher general level of productivity in the United States is to some extent due to this fact. It would be extremely difficult to estimate to what extent instrumentation affects production in general, but it is possible to assess its effect on individual chemical processes.

It is also very easy to appreciate that the same outlook which has led to the large demand for instrumentation has also led to high productivity. In particular, the eagerness to improve on what exists and the enthusiastic trial of any new thing which appears to possess merit, which is typical of the United States industries, must have a marked effect on the development of equipment of all types.

The neglect of instrumentation in so large a portion of industry in Europe is clearly due to a less progressive outlook, because the equipment has been available and awaiting application on a larger scale. For several reasons, which will be discussed below, this equipment has not until comparatively recently been as fully developed as in the United States. It has nevertheless been adequate to improve very greatly the operation of plants which lacked it.

At the present time very good equipment is available and its use is increasing, but not nearly fast enough.

It is important to stress that in comparing general levels it is easy to do less than justice to the progressive elements of both the chemical industry and the instrument-making industry in the many European countries concerned. It is therefore worth while to comment on the best European equipment and practice as compared to the best in America.

Comparison of the best instrumentation

It is easier to comment on practice than on equipment, because so much of the equipment used in Europe at the present time was developed in the United States. The performance of this equipment, provided the manufacturing methods are good, is of course the same as that of the same design in the United States. It is inevitable, however, that new designs developed in the United States appear on the market there somewhat earlier. Apart from this American designed equipment, it is probably fair to suggest that European *measuring* equipment is as reliable as that made in the United-States, while Europe is only now beginning to produce as well designed and developed process *control* equipment.

Europe's neglect of " application engineering "

In general therefore it can be said that the United States has led the way in instrumentation. Many American instruments are certainly based on measuring techniques and instrument designs worked out in Europe, but the United States has developed these techniques and designs for industrial plant use.

A very progressive instrument making industry, backed by a large home market, has carried the " engineering " of plant measuring instruments to a high pitch of achievement. At the same time it has pioneered the use of automatic process control and developed the pneumatic control equipment almost to finality.

Europe as a whole has been slow to develop the basic ideas and innovations which it originated in both fields. It has been almost equally slow in taking advantage of the fruits of American " application engineering " success in instrumentation.

Reasons for employing instrumentation

Measuring instruments

Instruments used for accountancy, for determining plant material balances and for metering raw material into the plant or finished product are necessary on all plants and are used as much in Europe as in the United States. Perhaps there is a tendency in the Unites States to pay less attention to material balances, so that more instruments may be used for this purpose in Europe.

Control instruments

The main difference arises with instrumentation used as the basis of plant operation. In the United States a great deal more automatic control is used than in Europe. The reasons put forward for its widespread use are naturally the same as those which have been stated so often recently in Europe, but great emphasis was placed, during discus-

sions with the firms visited, on the savings effected by replacing a man by an automatic controller. This is the direct result of the large increases in operator's wages in recent years.

The special problem of the chemical industry

While the installation of automatic control systems undoubtedly does effect considerable savings by decreasing the cost of operators in many industries, it is doubtful whether the possibility of making such savings in the chemical industry is any greater in the U.S. than it is in Europe.

It has been pointed out on many occasions in Europe that control systems are not generally installed on chemical plants primarily to decrease the number of operators, because this number is already the smallest required for dealing with emergencies on the plant. There seems no reason to doubt that the same argument applies to the American chemical industry, but of course it was not possible to substantiate this assumption without discussing it with users in the chemical industry itself in the United States.

There may well be, however, a tendency to employ more automatic control for the rather different reason that skilled operators are not easy to replace without incurring the considerable expense of a continuous training programme. Here again, however, it is difficult to see how this could materially alter the real position, because there must still be the same number of men on the plant to deal with emergencies, and they may, in fact, require more training because they are not continuously gaining experience in controlling the plant, if the controllers are doing this for them.

The main arguments for automatic control in the chemical industry

In any event, the more cogent reasons for using automatic control in the chemical industry are likely to be :

a) Smoother running — with consequent decrease in maintenance costs and shut-down periods.

b) Better control of product quality, less reject product.

c) The great difficulty (amounting in some instances to impossibility) of controlling the more complex modern processes by hand.

d) The greater reliability of the automatic controller in cases where explosion or other hazards will result from faulty control.

e) The possibility of decentralising the control of the individual variables by using controllers " on the line " when this is desirable; e.g. to eliminate transmission lags in the control system.

These reasons are all based on the economics of the process and lead logically towards instrumentation installation costs of 5 %, or as high as 10 %, of the total cost of the plant, depending on its nature and size.

These costs are in agreement with those for installations in comparable plants in Europe which have been fully instrumented.

Over-instrumentation

There is a danger of over-instrumentation if enthusiasm is allowed full play, and careful assessments of the plant economy are made to counteract this tendency.

There is evidence to show that many plants are purposely supplied with more than the economic number of instruments in order to facilitate the start-up and to experiment with the instrumentation itself to find the optimum arrangement. In such cases the instruments which are found to be unnecessary are at a later date removed from the plant and used for other purposes. This practice is also found in Europe.

Examination of potential savings by automatic control

It was stated that some of the large chemical companies employ specialists to study existing plants with the object of improving their efficiency by modified or extended instrumentation. The results of such studies were said to have brought about very considerable savings in many of the processes. The cost of the new instruments are often recovered by plant savings in a matter of months. Similar results have been obtained in Europe.

Factors leading to the rapid growth of the instruments industry in the United States

The large home market

There can be no doubt that the very large home market, and in particular the demand of the oil industry, has encouraged the instrument making industry to achieve its present capacity, which has been estimated to be of the order of $ 250 million per annum and which is still growing.

Interest and collaboration of the process industries

At the same time it is important to realise that the remarkable progress achieved would not have been possible without the characteristic willingness of American industry to try new things and to encourage and assist the makers to maintain constant progress in the design and development of new and better equiment.

Research and development strength

The makers, for their part, have studied the needs of industry very carefully and have built up competent research and development departments to provide new ideas and equipment to meet these needs.

It is not unusual for a maker to spend 5 % of his turnover on research and development. In some instances, very much higher percentages could be quoted, especially for new companies setting out to cover a specialist field.

Efficient service for maintenance

The makers have also provided efficient service to the user for the maintenance of their equipment and for tackling problems as they arise on the plant. This can only be done in a country as large as the United States by setting up local organisations in each industrial area.

Feedback of plant experience to the development department

The field engineers in these local organisations play a large part in keeping the makers informed of present problems and probable future requirements. Information thus fed back from the plant to the research and development laboratory is invaluable in guiding the development work on new equipment and application techniques.

Production in numbers

The bulk of the instrumentation is supplied to the process industries by not more than twelve large makers, each employing on an average some 1,500 to 2,500 men. These makers supply a wide range of equipment, but in some instances supplement their own range by using other makes of equipment which is only required in small numbers. The emphasis is placed on long production runs and great care is taken at the design stage to simplify manufacture.

Considerable expense is involved in " tooling up " for manufacture and a very large number of instruments must be sold to justify this expense. Since a competitor may at any moment produce a more attractive design, it is necessary to exert a very strong sales effort while the instrument is still ahead of the field. To the European observer it may appear that, in consequence, the industry spends considerably more on sales effort than would be considered economic in Europe. It might be thought at first sight that closer collaboration between user and maker might provide a more profitable method of approach. However, it must be remembered that in many instances the sales representative is also a well-qualified engineer, who can obtain valuable working experience from the user and feed it back to the instrument maker. In addition, it was stated that in many instances the sales representative acts in very much the same capacity as the service engineer does in Europe.

It would therefore be unwise to make any comments on the effort concentrated on the sales aspect. At the same time there is no doubt that the European instrument company would benefit if its sales representative were as experienced in technical matters as his opposite number in America is reputed to be.

Experience and competition

The large instrument firms are in continuous contact with the process industries and are able to apply the lessons learnt in one industry or factory to solve problems in others. They are also in constant competition with each other and, to maintain their sales, each must continually strive to produce better and cheaper equipment than his competitors.

As a result, consistency and reliability are not sufficient by themselves to capture a large share of the market. Most users agree that there is little to choose over a long period between the performance of at least five or six of the large makers' equipment. At any one time, however, one maker is usually in the lead by reason of some new development, which may bring a great increase in his sales. Users appear to change over quite rapidly from one maker to another in such circumstances and do not in general tend to rely for long periods on one maker.

The result of this strong competition is that each maker attemps to improve his equipment in every possible way, e. g. for ease of maintenance and use, in resistance to plant conditions, speed of operation, method of application and, certainly by no means least important, in appearance. The equipment produced is certainly a strong argument for a highly competitive system.

Points for special consideration in Europe

It must be admitted that in the past the European process instrument-making industry has suffered very severely by apparently neglecting practically all the points noted above as responsible for the American industry's success.

In particular it has neglected " application engineering ", i. e. the development of good ideas and laboratory instruments into plant equipment designed for plant needs and conditions. The same comment could be applied to many other branches of plant equipment engineering besides instrumentation.

It must be recognised, however, that to carry into practice these desirable ideas it is necessary to finance them. This requires a large market.

A large potential market has existed in Europe, but the process industries have been slow to realise their own needs. They must therefore accept a large measure of responsibility for the falling behind of their equipment-supplying industries, of which the instrument industry is one. In some countries a good start has been made to remedy this fault. The process industries are aware of their needs and have made them known. The instrument makers in these countries are taking advantage of the change and making rapid strides to make up for lost time.

The main purpose of this report would be fulfilled if it could bring the importance of this fact to the notice of industrial management in those countries which are not yet fully aware of the importance of instrumentation.

The large makers

As has already been seen, industry in the United States is based on a high degree of specialisation. The instrument industry is not an exception. The major firms discussed already do not specialise in products to the extent one might expect, but they do employ specialists in their various fields of activity. In their research and development this is especially true and every company has a specialist, often of international repute in his field, to lead a team working on automatic control.

To some extent also the company itself tends to specialise in the requirements of a particular industry. One of the firms visited was primarily interested in boiler plant instrumentation, another has had a long and close connection with the metal and furnace industries, a third with the oil industry. All, however, were well able to deal with problems in the chemical industry and possessed a fund of experience in solving them.

The small specialist makers

As would be expected, a number of small companies have come into being to deal with specialised needs not covered by the large companies. Built up around a nucleus of a few competent specialists, perhaps only one or two, they fulfil a very useful purpose.

Such companies are particularly active in exploring the new possibilities opened up by advances in physical research; for example, analysis by emission or absorption spectroscopy, high vacuum measurement, leak detection and, most recent, the radioactive isotope field.

There appears to be some tendency for such companies, when they become established, to spread their activities over a wider field. Although there seems scope for them to do so at present, it is not a trend which similar firms in Europe should follow without very careful consideration. The value of these specialist firms is their specialisation, and the manner in which they supplement the development and production of the larger companies.

Again it must be stressed that the success of these small firms depends on their capacity for development of new things and their particularly close contact with the industries they set out to serve. They obtain great assistance technically from the development departments of these industries and, it is very probable, a certain necessary measure of support by contracts of one sort or another. Here again, the active collaboration of user and maker is essential to success on all counts.

The engineering contractor's specialists

The large engineering contractors all have instrumentation specialists who have usually obtained a long and varied experience in the industries chiefly served by the contractor. These specialists are

continually ordering and installing new instrumentation and assessing its performance as the new plants are started up. It would be surprising if their views had not a considerable effect on trends of development. The makers certainly keep in close touch with them.

Specialists in the chemical industry

The large chemical manufacturing companies attach great importance to instrumentation and carry teams led by experienced specialists to ensure that the instrumentation is well designed, installed and maintained. They also carry strong teams for development work to meet the specialised needs of their processes.

The development staff of both the maker and the user are often in very close touch, so that any new equipment developed to prototype stage by the process specialist can be readily handed over to the selected maker for manufacture. Both benefit from the collaboration.

The needs of the chemical industry are often peculiar to itself or even to small sections, so that only a limited market may be available for the new equipment. Process information is also more likely to be a valuable secret than in many other large industries. Therefore the user must have his own development specialists to meet his new instrumentation problems.

Standardisation

Opinion was divided on the question of standardisation of the overall dimensions and fixing-holes of commonly used components and instruments. Those who opposed the idea usually gave one of two reasons. Either the idea was regarded as too difficult to put into practice, or as being undesirable as a cramping effect on development.

It was generally agreed that standardisation of terminology and symbols is very desirable and that if possible it should be carried out on an international basis.

Work on both types of standardisation is actually going forward under the auspices of the Recommended Practices Committee of the Measuring and Regulator Section of A.S.M.E.

Europe should make up its own mind on these questions and try to obtain international standards wherever practicable. European collaboration would be welcomed and, it is thought, must supply the driving force to achieve a significant rate of progress in obtaining international standards. It should be mentioned that a common standard dimensions for the separation of the flange faces of automatic control valves has been agreed between the United States and the United Kingdom.

Education in instrumentation

Maintenance mechanics.

The majority of the mechanics employed by the chemical industry to maintain instrumentation are very anxious to learn more about their

subject in order to obtain promotion. They have five main sources of information :

a) Internal works courses run by the chemical companies — and instruction manuals with specific application to the job.

b) Courses offered by the instrument-makers.

c) Local technical college evening classes.

d) Correspondence courses.

e) Text-books.

The internal works courses tend to stress job instruction and are meant to supplement the more fundamental and theoretical information obtained from the external courses.

There is a notable absence of any scheme for running courses in technical colleges with a national standard of content and achievement, and leading to a recognised certificate for the successful student. Another difference from European practice is the absence of apprenticeship for training mechanics.

Courses in the maker's works are given as broad a base as possible and are used by new recruits to the maker's own staff. They are naturally bound to show some bias towards emphasis on their own equipment. Indeed some of these courses are only intended to train process personnel in the use and maintenance of the maker's own equipment.

Graduates

Instrumentation is included by a large number of universities and technical colleges in their mechanical engineering and chemical engineering courses. The former tend to deal mainly with the basic principles of design, without any reference to the theory or practice of the instruments' application to plant control. The latter, however, make a special point of including this part of the subject as an integral part of the study of unit processes.

On paper the chemical engineering schools appear to give considerable instruction in automatic control practice, but the time available to cover the whole chemical engineering syllabus is too small to allow of much more than an introduction to the broad principles and to a few standard controllers.

A very notable experiment in teaching process control as a post-graduate course is being carried out at the Massachusetts Institute of Technology in the Electrical Engineering School.

The need for more training in instrumentation

In Europe graduates entering industry have in the past only rarely had a previous introduction to industrial instruments and have usually no idea of the importance and scope of automatic control. This is one aspect of the general need for better education in chemical engineering.

Those universities and technical colleges now teaching the subject

should be given every encouragement to extend their work and to include an introduction to process instrumentation in their syllabus.

Plant instrument maintenance

It is very important to know the cost of maintenance of different types of equipment if any estimate is to be made of the economics of a proposed installation. Unfortunately, there was no opportunity of studying maintenance methods at first hand on chemical plants and therefore little can be reported on this subject.

It was gathered however that maintenance costs are considerably lower for unit capital investment than in those European chemical factories which set out to achieve a high standard of reliability in their instrumentation; at the same time they are very much higher than in many European plants where maintenance is neglected.

Well-planned maintenance is most important. The ideal maintenance scheme will expend just enough money to ensure that the equipment gives an adequate performance. The chief difficulty in operating an economic maintenance scheme is to set a level of performance which is actually adequate.

In far too many European plants the instrumentation is badly neglected. Expenditure on " preventive " maintenance is thus very low (and the cost to the plant in loss of production correspondingly high). However reliable instrument equipment is, there are parts of it (especially those exposed to plant materials, e. g. sampling systems, valves, etc). which require routine attention. If this is not given sufficiently often and carefully, the system finally becomes erratic or fails completely.

It was gathered that American industry believes strongly in " preventive " maintenance, but does not spend as much upon it as those companies in Europe which set out to achieve a high standard of instrument and control reliability and consistency. Data are not available for judging how far this lower expenditure is due to more efficient working and organisation of the maintenance sections and how far to the level of performance considered adequate.

It does seem to be probable, however, that it is the American practice to be satisfied with consistency, without demanding absolute accuracy unless it is really necessary; and secondly, to replace old instruments by new one (of later design) with far greater readiness than might be thought in Europe to be economic. The hidden advantages of such a replacement policy are not easy to assess and it is suggested that it would be advisable for more European companies to consider the economics of their maintenance with special regard to the replacement of obsolete equipment, which it may be expensive to retain in operation from both the maintenance and production points of view.

Automatic control

The impression was given that the main objective of the instrument firms at the present time is to increase the speed of response of control

systems. They are therefore producing control units which can be placed on the plant near the detecting element, or, alternatively, they are developing new pneumatic transmission systems to reduce transmission lags (see Annex VI).

It is peculiar that the need for more rapid response has not focussed more attention on the development of electric systems. Leeds and Northrup appear to be the only makers with a three-action all-electric controller on the market. This is one field of activity in which Europe can fairly claim to have carried its developments at least as far as those in the United States, by the production of an all-electric three-action control system which is at present undergoing extensive plant trials. It is a very important indication of the post-war initiative of the European instrument industry that it should have produced a type of equipment which anticipates the users' needs, in spite of the controversial nature of the advantages claimed for electrical controllers.

The effort to produce quick response systems appears to have diverted the makers' attention to some extent, for the time being, from the investigation of other general fundamental problems of plant control, but a considerable amount of work of this type is proceeding at the Massachusetts Institute of Technology in the Electrical Engineering Department. The M.I.T. approach to process control is based on experience of the servo-mechanism field.

It is interesting to compare the approaches of those working in this field in America and in Europe. As might be expected from their servo-mechanism background, the M.I.T. workers have adopted methods which are thoroughly logical and sound (provided the basis plant data are available in sufficiently accurate form). On the other hand, these methods, require a high degree of mathematical and analytical ability for application to the design of specific control installations.

In Europe a diametrically opposite approach to the problem has been adopted. The problem has been attacked in a fundamental manner, using all available mathematical tools to carry out the analysis of the fundamental problems, but an attempt is made to present the results in a form which can be interpreted and applied to specific problems by the average plant engineer. The results, when presented in this way are recognised as being only good approximations, but they are sufficiently accurate for most plant applications. Where necessary, closer approximations can be made by a specialist.

It seems probable that this approach is the more suitable to obtain rapid development in Europe, because it does not involve the training of a large number of specialists.

Both approaches demand a much greater amount of plant data than is available at present, and again the methods of obtaining it differ. It is probable that each approach is best fitted to its own environment and certainly each will have a contribution to make to the final solution of the control problem as a whole.

The continuing increase in the use of automatic control

A trend already mentioned, but so important that it deserves repetition, is the continuing increase in the use of automatic control. As already stated, the reason most stressed by the engineering firms visited to explain this is the concern for rationalisation arising from the high level of operators' wages.

However, the impression was obtained that in the chemical industry itself the chief reason is probably that the quality of product demanded is always becoming more critical. Therefore to obtain this quality, and at the same time to minimise reject product, automatic control is essential, since it has been proved quite conclusively to be more reliable and consistent over long periods than the average human operator.

A second reason which was mentioned, and from European experience is known to be valid, is that some of the newest processes require the precise control of so many inter-related variables that it is almost impossible to control the plants manually.

Greater precision of control. Speed of response. Measuring units

From what has been said above it follows that increased precision of control is being, and will continue to be, demanded by the chemical industry. Therefore, much attention is being paid to the consistency and speed of response of the measuring units, since upon these must depend the ultimate quality of control.

Existing measuring units in general give sufficient consistency for plant requirements for the common measurements, temperature, pressure, flow and level. In many instances increased speed of measurement is needed, especially in temperature and flow control.

In temperature, the development of high speed, self-balancing potentiometers (indicators, recorders and non-indicating controllers) has emphasised the limitation imposed on the speed of measurement by the detecting element. Since the slow response of the detecting element is usually due to its protective sheath or pocket, work is directed to ensuring better thermal contact between element and pocket. New forms of element and sheath combinations can be expected.

In flow measurement, the commonly used mercury-filled manometer is responsible for very considerable slowing up of response speed. In fact, it can disguise important fluctuations of flow completely if they are sufficiently rapid. One approach to faster flow measurement is the diaphragm-operated measuring unit : it is believed that others are being developed.

An interesting development which might be mentioned at this point is the " telephone dialling " system of selecting measuring points for indication. This has been applied on an oil refinery with great success to deal with a temperature measuring system consisting of hundreds of

points. It was stated that the same system was about to be applied in the chemical industry to a plant manufacturing a new synthetic fibre, for the measurement of many hundreds of individual temperatures. An advantage of the system is that it eliminates the necessity of running the leads from each detecting element to the measuring unit. In this way much cost is saved in the original installation.

Speed of response — Transmission systems

Remote transmission of measurements from detecting element to measuring element or from measuring unit on the pipe line to the controller are also responsible for time lags in the control loop. They are being eliminated in two ways. In one, the controller, measuring element and detecting element are all located near each other on the plant. In the other, the pneumatic transmission systems are modified to give minimum time lag.

Much has been said in the past on the desirability of housing equipment in the control room, where it will not be exposed to plant conditions. The proposal to put the control and measuring equipment back on the plant might appear to be a retrograde step.

It is argued, however, that modern equipment is quite capable of withstanding plant conditions, if designed for the purpose, without needing additional maintenance. Plant experience of some of the new control units appears to establish this claim quite definitely.

Less common measurements

Considerable advances have been made in some of the less common measurements, but these have in the main been paralleled by similar advances in Europe. For example pH measurement has been improved in consistency in both the United States and Europe by development of better glass electrodes and better measuring systems. Electrical conductivity of solutions, gas analysis by radiation absorption methods and automatic titration equipment for plant use have also been considerably improved in both places during the last few years. They are still the subject of development work.

Radioactive isotopes are being brought into use for measurements of several types, e.g. thickness measurement for both inspection of vessel or pipe walls on site and also for continuous measurement of thickness of metal and non-metal sheets during production, measurement of the depth of a " fluidised " powder bed at high temperature. No application of radioactive " tracer " technique to flow measurement was discovered.

Changes in the control room

The tendency to place measuring and control equipment on the plant does not eliminate the need for a central control station. The measurements of the controlled plant conditions must be brought to a

central point so that a single operator can watch plant behaviour. Provision must also be made for the operator to influence this behaviour without going out to the plant to do so. Therefore instrument readings (or alternatively deviations from the desired value) must be transmitted to a central station and remote adjustment of the desired value must be provided.

There is also a tendency to demand fewer records of plant variables. Good pressure and level control, for example, are usually comparatively simple to achieve and the records are notorious for showing no significant departure from the desired value. The development of multi-point circular chart recorders also gives the possibility of reducing the number of recorders necessary.

The " telephone dialling " type of temperature installation will again effect a reduction in the number of indicators required.

Miniature indicators, recorders and controllers

Makers have been quick to appreciate the need for " miniature " instruments, to save space in the control room. Already several new designs of " miniature " indicators, strip chart recorders and controllers are available and in plant use.

One of the functions of the recorder is to show trends, and its importance in this respect remains for all but the easy control.

At the same time pneumatic transmission systems of higher speed are being developed to overcome transmission lags between controller and regulating unit, such as a diaphragm-operated control valve.

There is no doubt that the miniature instruments and smaller size control-room panels have met a need caused by the increase in plant size and consequent multiplication of instruments to be housed.

The graphic panel

The graphic panel is not a new idea, but it has only recently been introduced in its present, well-developed form to the chemical industry.

The graphic panel is best described by photographs (Annex VI). The object of the system is to place the instruments (which must be small) at the points of a flow diagram on the panel where the detecting or regulating unit is actually located on the plant.

The main argument in favour of this type of panel is that it assists very materially in the training of operators for new plants, particularly when these are complex.

Opponents of the graphic panel point out its inflexibility when changes in plant or instrument are required, and the higher initial cost. There is much to be said for this point of view.

It is probable that the two new types of panel will suffer many modifications before either becomes firmly established, and it may be that both will finally find a place in the chemical industry on different kinds of plant.

Conclusions

1. The chemical industry in the United States considers instrumentation a valuable aid to increasing productivity.

2. The general level of instrumentation is considerably higher than in Europe.

3. The rapid progress in instrumentation has been very much assisted by industry's willingness to try out new equipment and to assist development.

4. Less than a dozen makers supply the bulk of the process instrumentation demand of the United States industry. They are large enough to support really effective development teams.

5. Competition between these makers is keen and produces a very high standard of equipment and accelerates trends of development such as those mentioned in the report.

6. Makers try to discover new plant requirements and to design well-engineered equipment to meet them.

7. The large makers appear to be adhering to development of their standard lines of equipment and leaving the new specialised developments to the smaller specialised firms.

These conclusions led to the recommendations given below.

Recommendations

1. A determined effort should be made to draw the attention of industry to the value of instrumentation as a means of increasing productivity.

2. Means should be devised for disseminating information on the value of instrumentation among those who control policy in industry.

The problem is to find a means of converting management to the habit of mind which demands efficient instrumentation:

3. The chemical industry should make its requirements clear to the makers. The future demand for existing types of instruments and also the developments most required should be stated.

4. The makers should take every opportunity of widening their experience of industrial problems, throw more effort into research and development and pay particular attention to " application engineering " in their new designs.

5. Industry and the makers should attempt jointly to further standardisation of commonly used components and equipment, terminology and symbols, on a Europe-United States basis.

6. As the demand for instruments increases, established companies should be encouraged to extend their capacity; the mistake of having too many small new firms with inadequate development resources should be avoided.

7. On the other hand, small companies might with advantage be encouraged to cover specialised fields and so have a function complementary to the large companies.

8. The instrument-making capacity of countries already well advanced in the process field should be utilised by countries not in the same favourable position. In turn these countries might concentrate on building up the specialist type of company and so contribute their share to the general effort.

9. More contacts should be made between chemical industry instrumentation specialists in the various countries and a much closer liaison and interchange of views on instrumentation technique should be maintained between them.

VI

CATALYTIC PROCESSES IN THE PETROLEUM INDUSTRY

The Houdry process

The original Houdry catalytic cracking process is a batch process. A continuous flow of product is obtained by employing two or more sets of reactors operated on a schedule with at least one reactor on stream while the carbon is being burned off the catalyst in another.

The cracking process is endothermic, and the heat required can theoretically be provided by the combustion, during the regeneration stage, of the carbon deposited on the catalyst. The disadvantages of the original Houdry process are that the temperature of the catalyst is steadily falling during the reaction cycle at the same time as the activity of the catalyst decreases, that the thermal efficiency is relatively poor and that batch operation is complicated and expensive. For this reason the catalytic reaction cannot operate at optimum conditions of throughput and temperature and the yield and quality of the gasoline produced never reaches the maximum.

It is interesting to note that the hot gases from the regeneration of the catalyst are expanded through a turbine which drives the compressor for the inlet air and also an electric generator. This was stated to be the first application of the gas turbine in the United States. It has been of decisive importance for the economy of the original Houdry process.

The Thermophore process

By moving the catalyst continuously from the reactor to the regenerator and back again to the reactor the disadvantages of fixed bed catalytic operation have largely been overcome. The rate of flow of catalyst can be adjusted so as to reduce the quantity of carbon deposited and all the necessary heat of reaction can be transferred from the regenerator to the reactor. It is thus easier to regenerate the catalyst without having to heat it to such a high temperature that inactivation occurs. To achieve this, there is a tendency to increase the ratio of moved catalyst to oil; in some cases up to 15 parts of catalyst are now used

to one part of oil. The quantities of catalyst to be moved are thus very large; 175 tons of catalyst are moved per hour in older plants and up to 500 tons in new plants. The higher catalyst oil ratio enables the catalytic cracking processes to be operated with higher mean activity and better selectivity of the catalyst, with lower temperatures (and therefore increased yields of high octane gasoline), lower losses by carbon deposits and a relatively smaller production of cracking gases as by-products.

In the earlier designs bucket elevators were used for lifting the hot catalyst to the top of the reactors. These elevators, which operate at a temperature of 510°C (950°F) and are capable of handling 175 tons/h of catalyst, represent an outstanding achievement of mechanical engineering; but with the use of greater quantities of catalyst mechanical transport became impractical and is now beginning to be generally replaced by pneumatic transport.

The difficulty with pneumatic transport was to find the necessary flow ratio of gas to solid and the best aerodynamic conditions, including the need for avoiding erosion. By stroboscopic methods using 600 to 1,500 frames per second, it was found that the velocity and distribution of the 3 to 4 mm. pellets or catalyst grains in the gas stream could be made nearly uniform by suitable design of the ducts, with the result that the gas lift technique can now be used on a commercial scale.

With the high rate of catalyst circulation, it is now possible to use, without cooling, a regenerating chamber of large diameter but low height and with only two combustion zones instead of high towers of smaller diameter and with at least ten combustion zones; in his way the vertical distance through which the catalyst must be lifted is reduced, with correspondingly reduced power consumption.

A flow sheet of a Thermophore catalytic cracking plants is shown in figure 1.

Fluidised catalyst process

If a bed of solid particles is exposed to a vertical stream of gas the particles become separated from each other, and when the rate of flow of the gas is increased sufficiently, the bed of solid particles gradually acquires the character of a fluid. The fluidised solids exhibit good heat transfer with rapid elimination of temperature gradients. Translated into practice, this means improved temperature control and the possibility of maintaining reaction temperatures at their optimum values with correspondingly increased yields. The fluidised solids have the other important property oı being able to flow through pipes like liquids. Continuous transfer of solid to and from the reactor thus becomes technically feasible.

The principle of fluidisation was foreshadowed in the Winkler generator developed in Europe for the production of synthesis gas from brown coal for the production of ammonia. The full development of the

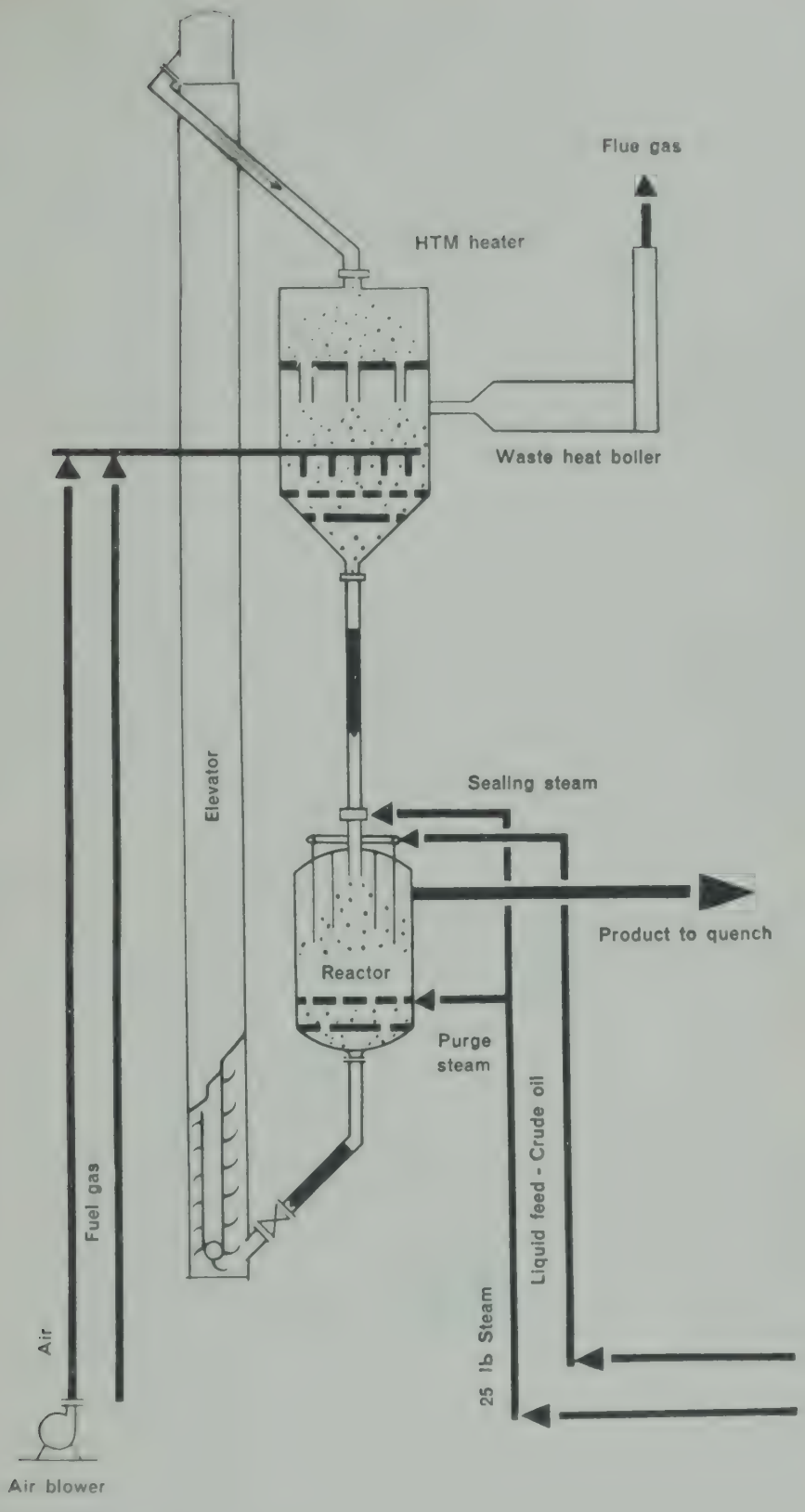

Fig. 1. Thermophore Catalytic Cracking.

fluidising technique came through its application to catalytic cracking in the United States. So far three applications have been developed :

Application to catalytic cracking

The first catalytic cracking plant of the fluid catalyst type was erected in 1942 at Baton Rouge for Standard Oil of Louisiana. The reactor had a diameter of about 14 m. In fluid catalytic cracking there is a continuous flow of powdered catalyst between the reaction and regeneration vessels. Compared with fixed bed catalytic cracking, the construction is greatly simplified. All the heat required by the process is provided by the heat of combustion of the carbon deposited. A simplified flow sheet of a fluid catalytic cracking plant is shown in figure 2.

Hydrocarbon synthesis

Synthesis of hydrocarbons with fluidised catalysts in a modified Fischer-Tropsch process constructed by the Hydrocarbon Research Co.[1] has been in operation for a short while at Brownsville, Texas, on a large scale unit with 350,000 tons/year capacity. In the Trenton laboratory of Hydrocarbon Research Co. pilot plants are in operation for further development. The Kellogg Co. is also occupied in pilot plant synthesis work.

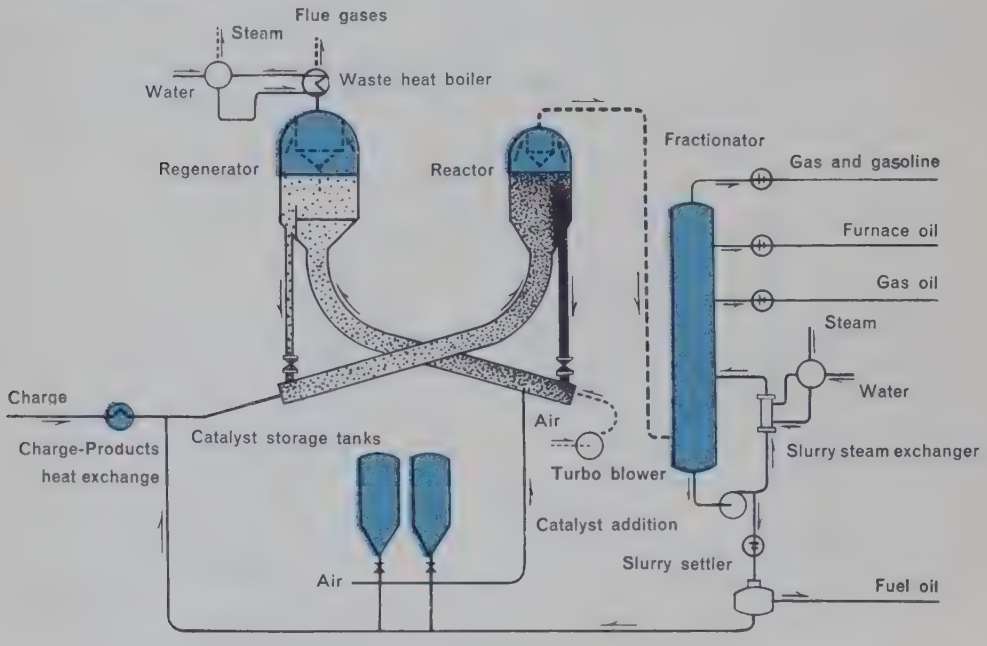

Fig. 2. Fluid Catalytic Cracking. (Figure supplied by Foster Wheeler Corporation.)

1. Firm visited by one Member of the Mission only.

The modified Fischer-Tropsch process, called the Synthin or sometimes the Synthol process in America, operates with catalysts based on iron. Kellogg are using a sintered iron catalyst ground to 10-100 microns. At Brownsville one member of the Mission was told that a powdered iron ore catalyst is used. The operating temperature is about 315°C, and the main products are a high octane gasoline and gaseous olefines with wax, alcohols and acids as by-products.

Other applications

In principle the fluidised catalyst method can be used for many kinds of catalytic processes; in particular the catalytic oxidation of naphthalene to phthalic anhydride has been developed on the pilot plant scale.

Miscellaneous technical problems

It should be noted that in fluidised bed operation the automatic control is much the same as in liquid operation i. e. fluidised substances are measured in the same way as liquids. Pilot plant operation in this field is of greater importance than in most other chemical engineering fields because many new problems have to be solved. Pressure drop, heat transfer, corrosion and erosion problems and the size of particles all require fundamental studies. For pilot plant work vessels up to 10 m. high and 10 to 60 cm. in diameter are used. Cyclones and ceramic filters are used for removing catalyst dust from the exit gas stream. The density of the fluid catalyst is about 0.5. Heat removal in the pilot plants is effected by means of jackets with boiling liquid, in commercial scale plants by multitube heat exchangers. Pilot plants for catalytic cracking by the fluid catalyst method were seen in operation at Kellogg, Foster Wheeler and Hydrocarbon Research Co.

Catalysts

Types of catalysts

In the American petroleum industry some 1,000 tons of catalyst are consumed daily, and the manufacture of this catalyst is a matter of great importance. Catalysts made from clay were stated to be less satisfactory because they contain iron and do not give a good product distribution. Synthetic catalysts based on aluminium silicate were manufactured in large quantities by the Houdry Process Corporation.

It is essential that the catalyst should show great resistance to attrition to enable the loss of catalyst to be kept at an economically feasible level.

Physical tests

Simple physical methods for predicting catalyst activity have long been sought without success, but the Mission learned that chemisorption

of quinolin at low pressures and high temperatures gave excellent indications of the behaviour of catalysts for the cracking of hydrocarbons. X-ray methods have only proved useful for detecting overheating of catalysts.

Catalyst shape and size

Different shapes and sizes are made to suit different processes. Cylindrical pellets are often used for the original fixed bed Houdry process, but have proved unsatisfactory for the moving bed process because the edges are easily knocked off. Spherical pellets with 3-4 mm. diameter are therefore produced for this purpose by Houdry. The fluidised catalyst process requires a finely divided catalyst, usually between 100 and 200 microns.

Conclusions

In conclusion it may be said that the moving bed and fluidised bed techniques have revolutionised catalytic processes in the oil industry in the United States and are likely to be widely applied also in the chemical and metallurgical industry.

These processes are described in great detail in a large number of recent papers in the American chemical engineering journals, and may therefore be expected to be well-known in Europe. It is sufficient here to refer to " Petroleum Engineering " by W. L. Nelson, 3rd Edition 1949, which gives numerous references to original papers.

Further applications of these techniques in European industry should therefore be considered.

VII

METHODS OF SEPARATING HOMOGENEOUS MIXTURES

The catalytic processes used in the petroleum industry yield very complex mixtures of reaction products, and the plants required for the isolation and purification of the final products are usually more complex and expensive than the reactors themselves. A large amount of work has been carried out in the United States to develop and improve these separation processes which form the essential complement to the new catalytic processes which have developed so rapidly in recent years.

Hypersorption

Development

The recovery of vapours by adsorption on active carbon or other suitable materials has long been known and used for such purposes as the recovery of benzene from coke oven gas, gasoline from natural gas or synthesis gas, solvents from air, etc. In all these cases a strongly adsorbable component is separated from a mixture with gases which are practically unadsorbable. The operation is usually a batch process with successive cycles of adsorption and stripping, but a plant with moving bed operation was installed in Europe as early as 1922.

The possibility of separating two gaseous components which are both adsorbed, but to an unequal degree, was first demonstrated in Europe on a laboratory scale. This method can be considered as an application of adsorption analysis to gases. For technical application continuous operation is desirable, and this was achieved in the United States by means of the fluidising or moving bed technique resulting in the so-called hypersorption process.

Principle

A flow diagram of the hypersorption process is shown in figure 3 which also indicates the temperature gradient in the hypersorber. The process is analogous to distillation, but with the important difference

that instead of being operated with a downward stream of condensed liquid in contact with the ascending vapours it is operated with a downward stream of active carbon with adsorbed gas compounds. This makes it possible to provide a reflux stream at ordinary temperatures even with gases of low molecular weight. The alternative in such cases would be fractional distillation at very low temperatures or high pressures.

The hypersorption process uses a moving bed of charcoal with a particle size of about 200 microns, moving slowly downwards, at a speed which can be controlled according to the amount of charcoal removed from the bottom of the tower by a pneumatic lift. The adsorption column has three sections : a cooling section on the top, an

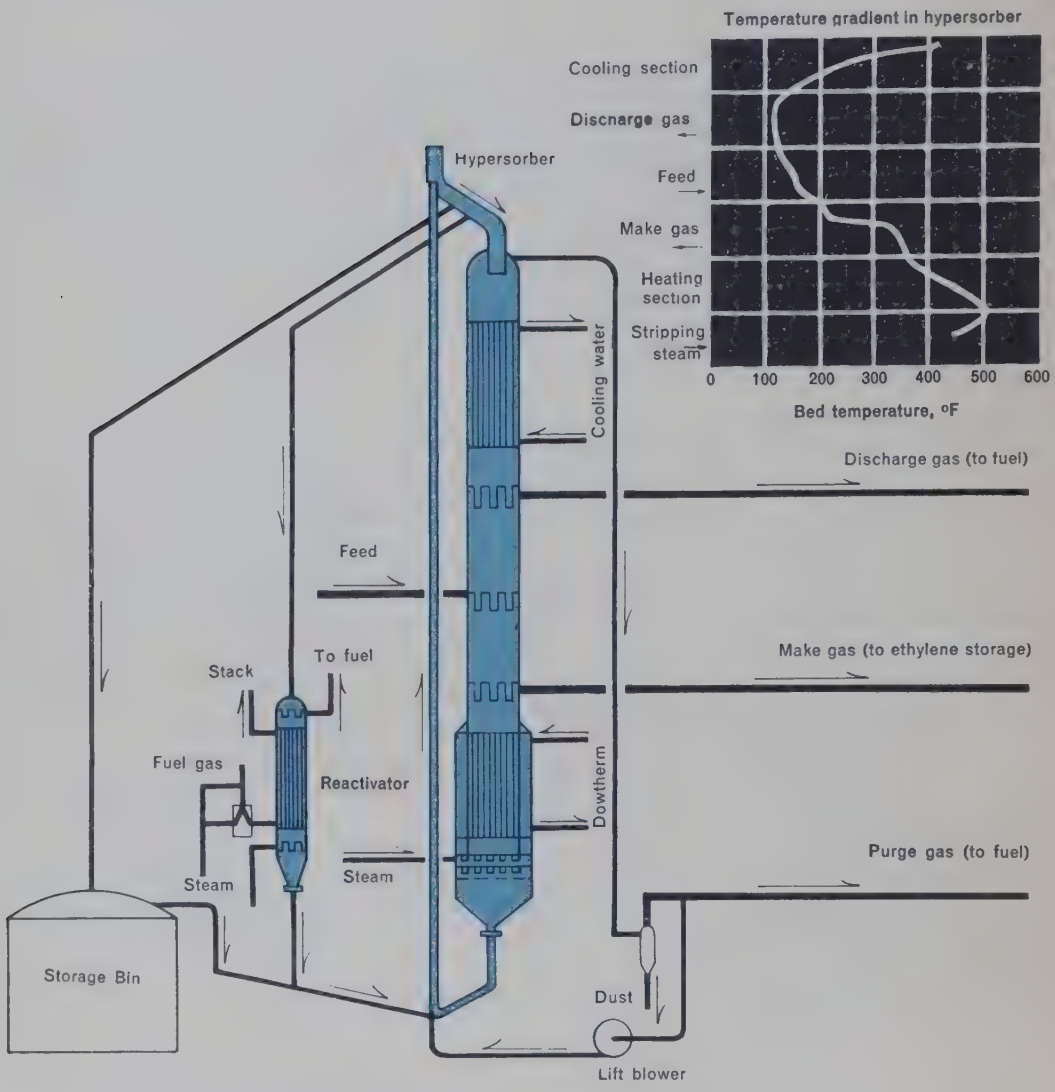

Fig. 3. Hypersorption. (Figure supplied by Foster Wheeler Corporation.)

adsorbing section in the middle and a heating and steaming section at the bottom. The feed enters in the middle of the tower and the concentrate leaves the stripping section below the lowest plate. A side stream of the charcoal cycle is moved continuously through a re-activator to maintain a constant activity of the charcoal load.

Applications

Several examples of applications of hypersorption are given below :

a) Separation of hydrogen of very high purity from practically any gas mixture containing hydrogen and hydrocarbons.

b) Removing ethylene and ethane from coke oven gas or any other gases such as cracking gases. The purity of the ethylene recovered is 92-93 % and the yield 98 %.

c) Separation of methane and nitrogen i.e. purification of synthesis gases or ammonia synthesis cycle gas.

d) Separation of carbon dioxide from combustion gases.

e) Acetylene recovery from partial combustion of methane.

It may be mentioned that it is also possible to obtain by this process several fractions in side streams containing high concentrations of the different compounds of the gas mixture used.

The results of ethylene recovery from gases from a cracking unit can be seen in the Table 3.

Table 3. Ethylene recovery from cracking unit gas

Composition in per cent by volume.

	FEED	TOP PRODUCT	SIDE CUT	BOTTOM PRODUCT
Hydrogen	22.8	47.0	—	—
Methane	32.6	57.1	0.1	—
Acetylene	1.1	—	3.0	—
Ethylene	34.0	0.1	90.9	0.2
Ethane	2.1	—	5.6	
Allene	0.2	—	0.2	3.4
Propylene	5.3	—		92.8
Propane	0.1	—	—	1.8
Hydrocarbons	0.1	—	—	—
Carbon monoxide	1.5	2.6	—	—
Carbon dioxide	0.2	0.2	0.2	—

Application

Solvent extraction is widely used both in America and in Europe for such purposes as refining of lubricating oil, production of animal and vegetable oils and extraction of vitamins, antibiotics and hormones. One American development is the Solexol process which uses liquid propane near the critical temperature as solvent. This process was claimed completely to decolourise and deodorise animal and vegetable oils with a yield of 98 %. Refining of lubricating oil by extraction with phenol-cresol and propane was also seen. In a second stage methyl-ethyl-ketone is used for dewaxing the lubricating oils. Furfurol has found considerable application in the United States for extraction of lubricating oils of high stability.

As a successful competitor to fractional distillation the unit operation of solvent extraction is widely used in America as well as in Europe for the recovery of acetic acid from waste liquors. Some 700,000 tons were stated to be recovered every year in America by this method. Even dephenolation of waste water can, it seems, be done economically in this way.

Conventional type equipment

On an industrial scale the usual packed or spray type of columns are not very efficient. The perforated plate type of column was stated to be more efficient where it could be used, mainly because the drops are reformed at every plate and it is an established fact that the extraction efficiency is high when the drops are in process of formation. But even for this column the plate efficiency was stated to be of the order of only 15-20 % of theoretical efficiency and in some cases might even be lower. The Scheibel column which is mechanical and composed of alternate sections of agitation and rest (for the separation of the phases) was also discussed, the information available was insufficient to allow closer consideration of its merits.

The centrifugal extractor

One of the most original and successful developments studied by the Mission in America was the Podbielniak centrifugal extractor. This machine was originally developed for fractional distillation, but did not find any wide use for that purpose; it owes its success to the rapidly expanding antibiotics industry in the same way as the fluidising and other techniques owed theirs to the rapidly expanding petroleum industry. For optimum results in the extraction of penicillin a multi-stage process must be used to secure good recovery; it must be rapid to avoid decomposition, it must remain unaffected by the small amounts of finely divided solids, which are precipitated during the operation, and by the pronounced tendency of the liquids to emulsify. These very difficult

conditions could not be met by any previously existing equipment, but were adequately fulfilled by the centrifugal extractor. About 90 % of all penicillin produced today is extracted with Podbielniak machines, and this extractor is already in operation in most of the countries of Western Europe.

The centrifugal extractor which is shown diagramatically in figure 4 consists of a rotor fitted with a steel strip formed into a spiral and surrounded by a cylindrical bowl. Both liquids enter through channels in the shaft, the heavier one being led to the central end of the spiral and the lighter one to the end near the periphery. The liquids, which enter under pressure are forced to flow at relatively high speed past each other in the narrow spiral. Emulsification is so effectively prevented by the centrifugal force of 2,000 to 5,000 g. that the machine will handle liquids whose densities differ as little as 0.02. The contact between the two liquids is excellent, and the extractor is claimed to give 8-12 theoretical stages with the ternary system n-butylamine-straight chain naphtha-water. The standard types are built for capacities from 0.23-23 m^3/h (50-5,000 gal/h) of the combined streams. The machine is extremely compact, particularly in comparison with extraction columns of conventional design.

The field of application of the centrifugal extractor has now been extended to cover such processes as the extraction of other antibiotics from fermentation liquors, of caffeine from coffee extract, hormones,

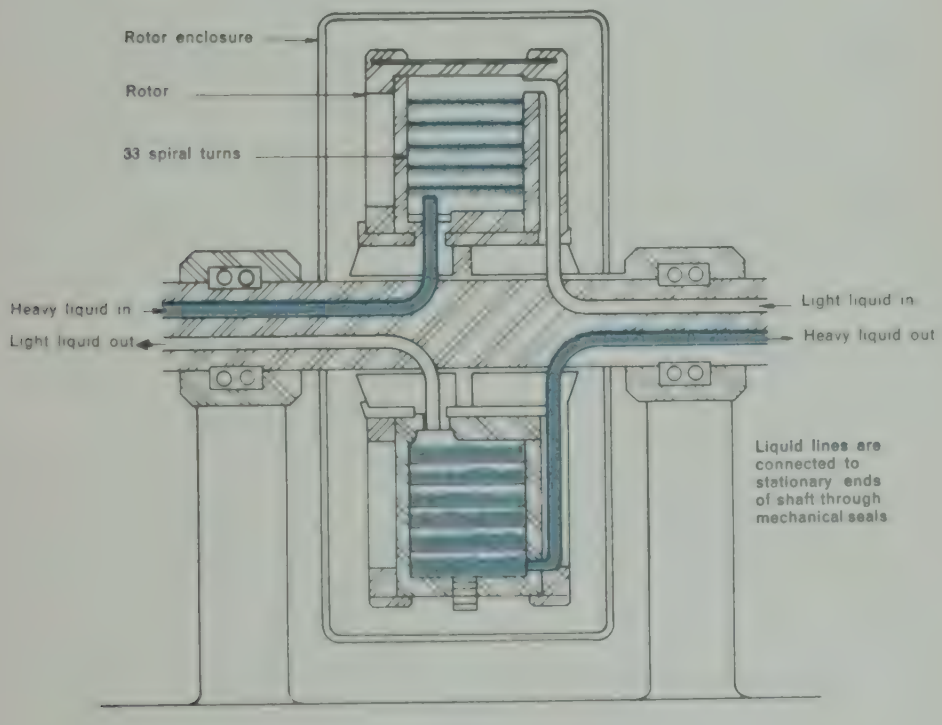

Fig. 4. Podbielniak Centrifugal Extractor.

vitamins, etc. A plant was stated to be in construction for the extraction of lubricating oil with furfurol.

The most important recent development of the centrifugal extractor has been to improve its ability to handle solutions containing larger quantities of solids. The claim was made that penicillin broth could, if desired, be extracted without prior filtration, although this may not be economical. Aqueous suspensions of liver and brain can also be handled by the machine.

For many applications the high extraction efficiency of 8-12 theoretical stages offered by the standard types is unnecessary, and by reducing the efficiency to about 2 theoretical stages the capacity can be greatly increased. Extractors capable of handling up to about 96 m^3/h (20,000 gal/h) of the combined streams are now available, thus making the machine more attractive economically for applications in the petroleum industry.

Distillation apparatus

Plate columns

Plate columns are still the most generally used, and some of those seen during the visit to the Sun Oil refinery were very large. In the oil industry columns about 100 feet high and over 10 feet in diameter are frequently employed. The tendency is to leave a considerable distance, usually about two feet, between the plates in order to facilitate cleaning and to avoid " priming ". It will be remembered that this phenomenon consists of the transference, by the rising vapour, of fine particles of liquid from one plate to the plate immediately above, and results in a decrease in the efficiency of each plate.

Systematic trials have been carried out in the United States in order to determine all the working coefficients necessary for designing a distillation column to produce a given result. Particular attention has been paid to pressure drop and flow limits, and to the effect of vapour velocity, the shape of the bubble caps and the layout and height of overflows etc., on the efficiency of the plates.

Experimental columns with sightglasses and interchangeable plates have been used in order to determine the best design for the plates. It should be noted that the position of the overflows controlling the flow and circulation of the liquid on each plate becomes more important the larger the diameter of the columns. The height of the overflow should, in principle, maintain the depth of the liquid layer on the plate so that there is proper contact between vapour and liquid. With increasing column diameter, however, the volume of liquid becomes larger and the path along the plate longer, with the result that a hydraulic gradient is set up on the plate. The usual solution to this difficulty for large diameter columns is to insert a series of overflow ridges which act as baffles and provide successive falls in level. Each section of the plate will thus have a well-defined liquid depth which prevents the formation of channels.

Some designers prefer to tilt the plate itself, but it appears that this solution, although capable of giving excellent results, has certain disadvantages likely to cause trouble for technicians not familiar with the process.

It can be seen from the foregoing that only questions of detail are involved, in particular, modifications to the shape and dimensions of the bubble caps or the position and number of overflows; there has been no fundamental change from what is already current practice.

It was considered in the United States that perforated plate columns deserve more consideration, as their instability of operation, which is the general criticism, is in reality much less serious than alleged. These columns are not expensive and are most efficient.

Columns fitted with Kittel plates prevent priming and ensure proper circulation of the liquid even in columns of very large diameter; they are however, not sufficiently flexible.

Conventional packed columns

During the visits, rather divergent opinions were expressed concerning the efficiency and advantages of packed columns. On the whole, interest seems to be reviving in these columns owing to a better knowledge of their limitations and of the reasons for the inadequate efficiency of certain types which reflected discredit on the others.

In the first place, the liquid constituting the reflux must be equally distributed over the whole surface of the column packing. The packing must also discourage the formation of channels and in particular must prevent the liquid from flowing towards the walls of the column. It is clear that if the liquid trickles on to the walls, this will interrupt exchanges between liquid and vapour and will nullify the efficiency of the process. In order to overcome this difficulty, it is recommended that the reflux liquid be redistributed over a drop of two to four times the diameter of the column. With this precaution good results would be obtained even with Raschig rings.

The shape of the packing makes it possible to reduce the tendency of the liquid to flow towards the walls; similarly the manner of loading the packing in the column influences its general effect, especially in the case of Raschig rings, and can even prove an effective method of guiding the liquid towards the centre.

Packing dimensions are determined in relation to the diameter of the column to be built. Raschig rings are still fairly common in the United States, and their maximum diameter is 3 inches.

The use of fine packing gives a large surface per unit volume of the column and the fractionating efficiency generally increases as the size of the packing decreases. To be effective, however, the available surface must be wetted with liquid. This becomes increasingly difficult as the packing dimensions decrease; the surface to be wetted becomes larger

whereas the liquid available for wetting becomes smaller since the fine packing becomes more compressed and offers greater resistance to the passage of vapour. The problem is therefore to design a packing with a large surface requiring the minimum liquid for complete wetting.

The Stedman column

Considerable progress was made by the introduction of the Stedman packing constructed of wire gauze, which has the important property of requiring little liquid for complete wetting. The gauze is formed into small cones stacked very close together as shown in figure 37 p. 209. The liquid flows very evenly and follows a broken, but more or less vertical course resulting in very large liquid-vapour exchange surfaces. Good initial distribution of the reflux liquid at the top of the column is ensured by a set of round bubble caps, fed from a central tube, producing a spray in the shape of a circular crown.

The Stedman column has revolutionised laboratory fractionation and made it possible with relatively small laboratory columns to obtain fractionating efficiencies equal to those obtained with the largest and most efficient industrial columns. For laboratory distillation the Stedman packing has now largely been replaced by other and still more efficient types, also constructed mainly of wire gauze, such as the Podbielniak " Heli-grid " packing, the Dixon gauze rings and the Watson double gauze packing. These last two types have been developed in Europe.

Industrial Stedman columns have been installed which give refining efficiencies corresponding to about 100 theoretical plates. According to the designers, this type of column is likely to develop considerably in the future. No information was available to the Mission about industrial applications of the other types of gauze packings, and critical comparisons cannot therefore be made at present.

With the possible exception of the Stedman column, packed columns find their widest application for the scrubbing of gases or vapours with liquids. Plate columns are very attractive for use in distillation, because even with a small liquid load the problem of liquid distribution is practically non-existent, and the efficiency varies much less with the rate of distillation than for packed columns.

Podbielniak centrifugal distillation plant

The Podbielniak Corp. demonstrated a very original development in the field of distillation which does not yet seem to have received practical recognition.

The reasoning which led to this apparatus, was as follows : In laboratory rectifiers with a high analytical efficiency, the difficulty lies in getting the reflux to descend quickly enough against the flow of rising vapours. The two fluids circulating in opposite directions are thus impeded and even halted if the packing is so fine as to obstruct a large

part of the cross-section of the tube in which the distillation is taking place.

The Podbielniak Corp. therefore considered that the liquid could be forced to circulate despite the resistance of the vapour by using a rotary apparatus turning sufficiently fast to produce the required centrifugal force.

This apparatus, which subsequently led to the Podbielniak solvent extractors, already dealt with in this report, is composed of a rotor along the axis of which the liquid and the vapours are delivered. The liquid is fed to the centre of the rotor and the vapours to the periphery. Rotation then compels the fluids to flow in opposite directions; the apparatus is divided into compartments with numerous baffles in order to obtain a systematic effect.

It is also possible to provide for reflux and to assemble several units in order to effect tappings at various points.

The disadvantage of such distillation apparatus seems, however, to be the difficulty of effecting heat exchanges. As the apparatus is comparatively small, because of its efficiency, it is difficult to see how there can be much difference in temperature between the incoming vapour to be purified and the boiling liquid acting as a reflux (the whole equivalent to a " concentration " column).

Only one large-scale application of this process is as yet reported, and it is therefore advisable to wait until the inventors have determined the proper conditions for using this revolutionary technique; it may perhaps prove of special interest in solving difficult problems of distillation in which there is little difference between the boiling points of the fluids to be treated.

It should also be remembered that the centrifugal distillation plant is mechanical and therefore relatively expensive, and that it has to compete with conventional industrial columns of high efficiency and capacity.

Podbielniak columns for laboratory distillation

These columns, which are world famous, are designed to permit automatic or semi-automatic distillation of the most varied mixtures.

The Podbielniak Corp. has shown that to obtain good fractionation very fine packing must be used in order to secure close contact between the vapour and the descending liquid. The vapours to be analysed must also meet an abundant reflux of condensed liquid; the more difficult the separation to be effected, the greater the volume of the reflux. A small, electro-magnetically activated teflon valve regulates the rate of flow while the rest of the distilled liquid is turned back at the top of the column. Heat radiation losses are avoided by enveloping the column in a vacuum jacket wich reflecting screens of polished silver.

With such columns it is possible to separate products with very similar boiling points. Articles, to which reference can be made, have been published on this subject.

Some aspects of the method adopted for the operation of Podbielniak laboratory columns might with advantage be applied industrially, as for instance the automatic control for drawing off a pure product, operated according to the difficulty of separating that particular product, by an impulse transmitted from a thermometer placed at an intermediate level in the column.

Use of distillation to obtain new results : extractive distillation

As already mentioned, extractive distillation was put forward as a new and effective method of solving certain difficult problems in the separation of complex mixtures. Lummus and Koppers, in particular, stressed the importance of applications of this technique during recent years.

Principle

The principle of this technique is as follows :

To separate two liquids A and B with practically the same boiling points or which are likely to yield an inseparable azeotropic mixture, a third substance C, is added, less volatile than A or B, and a good solvent for one of them. The addition of C therefore causes a change in the relative vapour pressures of A and B which enables them to be separated by distillation.

By measuring the relative pressures of A and B in the presence of varying quantities of C, it is possible to determine in advance the conditions most favourable to good separation.

This method has long been used in Europe for the separation of the azeotropic mixture of ethyl acetate and ethyl alcohol. In this case water is added as component C in order to reduce the relative vapour pressure of the alcohol in relation to the fairly constant vapour pressure of the ethyl acetate. Another well-known and old-established process is the separation of the azeotropic mixture of nitric acid and water by extractive distillation with sulphuric acid as component C.

Separation of toluene from methylcyclohexane

An example of extractive distillation mentioned was the separation of toluene from methylcyclohexane, products which have practically identical boiling points. Phenol is added as component C, which reduces the relative vapour pressure of the toluene in relation to that of methylcyclohexane.

Separation of butadiene from C_4-hydrocarbons with furfurol

As another example, the separation of butadiene from C_4-hydrocarbons with practically identical boiling points was demonstrated to the Mission. Furfural is used as component C. This separation is

of considerable interest industrially for the preparation of Buna synthetic rubber.

Furfural is a better solvent for butadiene than for the other C_4-hydrocarbons in the mixture and thereby lowers its relative volatility.

The gaseous mixture containing the butadiene is delivered to a column of about 100 plates and operating at a pressure of 5 kg cm², so that cold water can be used as a condensing agent.

The furfural flows in near the top of the column and descends towards the bottom, carrying with it the butadiene which tends to dissolve more easily than the other gases.

Slight heating at the foot of the column drives the butane and the other C_4-hydrocarbons to the top where they are taken off as top product. Part of this is condensed and turned back as reflux to meet the rising vapour containing butadiene, which is finally carried to the foot of the column by the furfural. This mixture of furfural and butadiene is delivered to a second column where it is split into its components by slight heating. The recovered furfural is used over again indefinitely. This process has been evolved by Lummus in co-operation with Philips Petroleum.

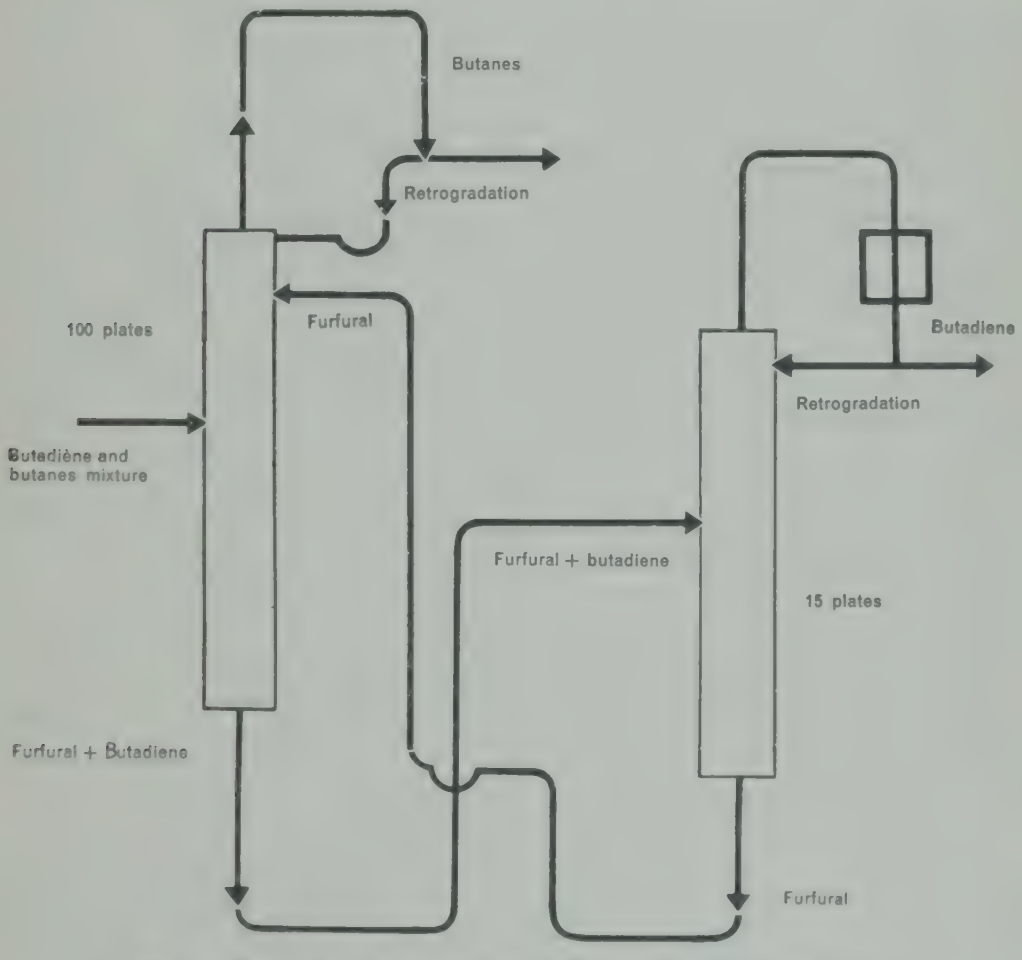

Fig. 5. Separation of butadiene from C_4 hydrocarbons with furfural.

Separation of butadiene from C_4-hydrocarbons with dichlorethyl ether

The Mission also studied the separation of the following mixture obtained from the catalytic dehydrogenation and dehydration of ethyl alcohol by the Lebedev method for preparing synthetic rubber.

COMPONENTS	PROPORTION IN MIXTURE %	BOILING POINT °C
Carbon monoxide	0.1	
Carbon dioxide	0.1	
Propylene	0.2	
Ethylene	1.25	
Product recycled } butylene	0.5	from — 5.5 to — 3.9
Butadiene	6.9	— 4.4
Acetaldehyde	12.0	20
Ethyl ether	6.0	35
Ethyl acetate	1.0	55
Ethyl alcohol	56.0	78
Water	13.0	100
Acetic acid	0.25	118
Oils	0.75	118

For the separation of this complex mixture extractive distillation, separation of azeotropic mixtures and various scrubbings were used in succession, and finally the various components were separated as pure products. This could be achieved with dichlorethyl ether, ethyl ether, ethylene glycol and finally alcohol as separating agents. This is a good example of the almost unlimited problems which can be solved by modern distillation methods.

The vapours from the catalytic furnaces are delivered to a condenser which allows the gas to pass and stops most of the vapours; the condensate obtained is rich in alcohol and contains all the heavy impurities.

The gaseous fraction is treated as follows : it is first scrubbed with alcohol in a column subjected to a low pressure of about 3.4 kg/cm^2. Almost all the butadiene remains in the alcohol, while a mixture of gases consisting of CO_2, CO, ethylene and propylene is released. As this mixture takes with it a certain amount of alcohol, it is scrubbed with cold water under low pressure before being discarded.

The ethyl alcohol containing butadiene in solution is treated in another column but the butadiene thus separated is still impure. It contains other C_4-hydrocarbons and, in addition, acetaldehyde vapours owing to the existence of an azeotropic mixture acetaldehyde-butene.

This aldehyde is removed by scrubbing with cold water in a special column under low pressure and the acetaldehyde thus separated is then recovered by distillation, as it must be recycled to the catalytic furnace.

The purified gaseous mixture thus consists of butadiene plus C_4 hydrocarbons whose boiling points, given below, are very close together :

	BOILING POINTS °C
Isobutane	— 11.7
Butane	0.6
Isobutene	— 6.9
Butadiene	— 4.4
n-Butene	— 0.5
Butene 2 trans	1.0
Butene 2 cis	2.5

This mixture is then treated by extractive distillation. Dichlorethyl ether is used as a solvent to reduce the relative vapour pressure of the butadiene. The latter is finally recovered almost completely.

Now follows the separation of the heavy impurities contained in the alcoholic condensates from the first separation of crude gases. Complications have to be expected owing to the existence of several azeotropic mixtures which hinder distillation. These mixture are as follows :

Butene - acetaldehyde
Ether - acetaldehyde
Alcohol - ethyl acetate

Extractive distillation in the presence of water is used to break down these azeotropes. The butene and acetaldehyde recovered are recycled to the catalytic furnaces.

The tailings consist of an aqueous solution containing oils which can be decanted. The oils are separated and the aqueous solution treated by ether extraction in order to recover the acetic acid in its anhydrous form.

Naturally, the number of columns in continuous operation required to carry out such complex work is considerable; Lummus referred to 48 columns used in a complete separation plant of this type.

Conclusions

1. For the continuous separation of gas mixtures by adsorption the moving bed technique has been developed and has found several important applications.

2. The centrifugal extractor has revolutionised the manufacture of many antibiotics, and is now finding wider application in the chemical and possibly even in the petroleum industries.

3. There has been no fundamental change in the design of standard distillation columns in the United States during the last 10 years.

4. The application of distillation in the United States has developed very rapidly, particularly in the petroleum industry for crude oil and as a necessary complement to the new catalytic processes. Certain modern

methods of synthesis yield very complex mixtures necessitating the use of distillation plants with many columns.

5. The technique of extractive distillation has been intensely studied and developed and has found many applications.

6. The chemical industry in Europe should follow closely the American development of methods of separating homogeneous mixtures, and to a greater extent adopt the improvements made for increased efficiency, particularly with regard to hypersorption, centrifugal extraction and extractive distillation.

7. Further attempts should be made in Europe to utilise on the industrial scale the amazing improvements made in laboratory distillation apparatus by increasing the vapour-liquid exchange surface, in particular by using packings constructed of easily wettable wire gauze.

A wider application of the sieve-plate column should be considered in Europe both for extraction and for distillation.

VIII

HEAT EXCHANGE

Heat transfer constitutes an essential part of practically all processes of the chemical industry, and efficient heat transfer with a minimum of capital expenditure is often the decisive factor in the economics of a given process.

The most important recent single development which has reduced capital costs of heat transfer equipment is the increased use of radiant heat in modern pipe stills for vapourising oil and solvents.

Standard heat exchangers

In the United States, in all types of chemical plants and oil refineries, heat exchangers are very important parts of the total equipment; some 35 % of refinery equipment consists of heat exchangers. Various firms specialise in their manufacture and most of the construction firms buy their heat exchangers from them. The tube diameters are standardised, the necessary capacity being in general obtained by using different lengths and arrangements of these standardised tubes.

Increased use of radiant heat transfer

It is characteristic of modern developments in heat engineering that radiation type heaters are used more and more for the transfer of heat from burning oil or pulverised coal. In 1925 about 25 % of the heat transferred in a pipe still or boiler was transferred by radiation and 75 % by convection; by 1950 the proportions were reversed. Nearly all heating and evaporating of oil and solvents in pipe stills is now mostly done by radiant heat.

The Babcock Wilcox Company demonstrated the recently-developed radiation type boiler with cyclone burners for pulverised coal. In this design the coils surround a circular combustion chamber into which coal, crushed to pass a 4-mesh screen, is introduced together with the necessary air. The temperature is so high that the slag can be removed in a molten condition. To give improved heat transfer the steam tubes

are fitted on the outside with steel studs, fixed by resistance welding. To protect the tube material the tubes are encased in a layer of plastic chromium ore with a very high softening point and high thermal conductivity.

The development in this field can be illustrated by the following figures. To generate 1 kWh of electric power, about 2.7 kg. (6 lb) of coal were needed in 1900, but only 0.39 kg. (0.85 lb.) in 1950.

The present upper limit of boiler construction in America was stated to be a unit operating with a pressure of 186 kg/cm² (2,650 lb/sq.in.) gauge and a steam temperature of 565°C (1,050°F) and with a capacity of 420 tons/h. A new unit with a steam temperature of 592°C (1,100°F) was stated to have been planned and its construction decided. This is considerably in advance of European practice.

Heat transfer with surface boiling

If a liquid is to be heated to a temperature below its boiling point the rate of heat transfer can be greatly increased by maintaining the tube wall at such a high temperature that the liquid boils in its vicinity. The vapour formed will, of course, quickly condense when it gets mixed with the colder liquid near the centre of the tube and thus acts as a heat transfer medium. The Mission was informed that heat transfer rates of the order of 3 to 14 million kcal/h,m² (1-5 million BTU/h,sq.ft.) could be achieved with surface boiling as compared with the normal rate of about 40,000 kcal/h,m² (15,000 BTU/h,sq.ft.) This technique has recently been intensively studied in the United States particularly in connection with atomic energy programmes. Although no industrial applications were disclosed to the Mission there can be little doubt that chemical engineers will soon take advantage of this recent extension of our knowledge.

Heat transfer media

Whenever a heat-sensitive material has to be heated it is essential to transfer the heat from the furnace to the reaction vessel by means of a suitable heat transfer medium. Water in the form of steam is generally used up to 180-200°C but above these temperatures the pressure becomes high enough to justify consideration of other media with lower vapour pressures.

The various heat transfer media used in the United States are well known in Europe, but the choice for a given application often seems to differ somewhat in the two continents. The higher pressures associated particularly with the use of water or steam at high temperatures appear less of a deterrent in Europe than in the United States, apparently because the American code requirements for high pressure equipment are stricter than the European specification and are more apt to result in excessive wall thicknesses in pipes and equipment.

Dowtherm

Next to water, the eutectic mixture of diphenyl and diphenyl oxide which in the United States is called Dowtherm, after the Dow Chemical Company, is the most extensively used heat transfer medium for the temperature range 180-360°C. Dowtherm A has also found a wide application in Europe. Dowtherm E, dichlorobenzene, can be used only up to about 260°C and is therefore of less interest, particularly in Europe.

The most important thermal properties of these heat transfer media are compared with water in Table 4 and figure 6.

Table 4. PHYSICAL PROPERTIES DOWTHERM VERSUS STEAM

	WATER	DOWTHERM A 73.5 % DIPHENYL OXIDE 26.5 % DIPHENYL	DOWTHERM E INHIBITED ORTHODI-CHLORO-BENZENE
Chemical formula	H_2O	$(C_6H_5)_2O$ $(C_6H_5)_2$	$C_6H_4Cl_2$
Molecular weight	18	170 154	147
Specific gravity at 212°F	9584	.9970	1.181
Relative densities of saturated vapours not corrected for temperature :			
1. Ratio to water at atmospheric pressure	1	7.0	7.3
2. Ratio to water at 50 lbs/sq.in. absolute pressure	1	6.9	7.5
3. Ratio to water at 100 lbs/sq.in. absolute pressure	1	6.6	8.1
Melting point °C	0.0	12.0	— 21.5
Melting point °F	32.0	53.6	— 6.7
Boiling point °C (Atmospheric pressure)	100.0	257.4	178
Boiling point °F (Atmospheric pressure)	212.0	495.8	352
Specific heat of liquid at respective boiling points (BTU/lb/ft.)	1.005	.63	0.413
Heat of vaporisation at respective boiling points (BTU/lb.)	970.2	125.00	118.9
Cubical expansion coefficient (32-212°F)	.00024	.00043	cu.ft/lb/F = 0.00000605 cc/g/C = 0.00068
Abs. viscosity of liquid at 212°F (Centipoises)	.284	1.0	0.54

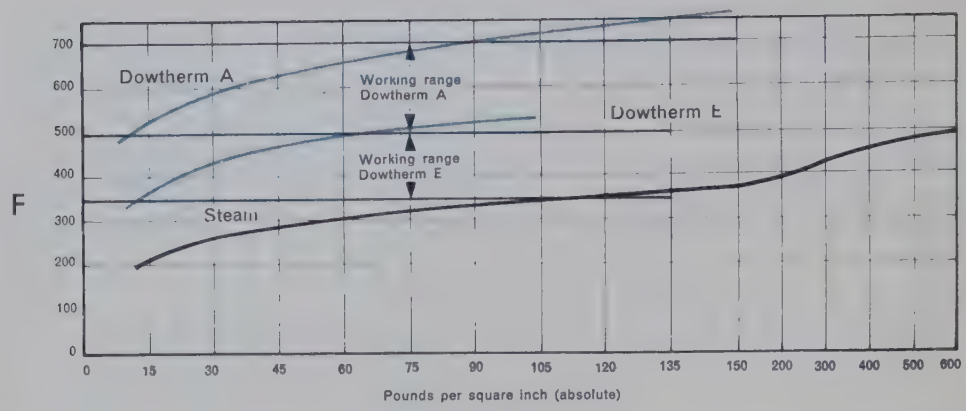

Fig. 6. Vapour Pressure of Dowtherm versus Steam. (Figure supplied by Foster Wheeler Corporation.)

Dowtherm is usually used as a condensing vapour, but in special cases also as a circulating liquid. Dowtherm is difficult to pump and gravity circulation is preferred wherever possible. There are, however, pumps which are claimed to handle hot Dowtherm satisfactorily. A dual medium heating system using Dowtherm is shown in figure 7.

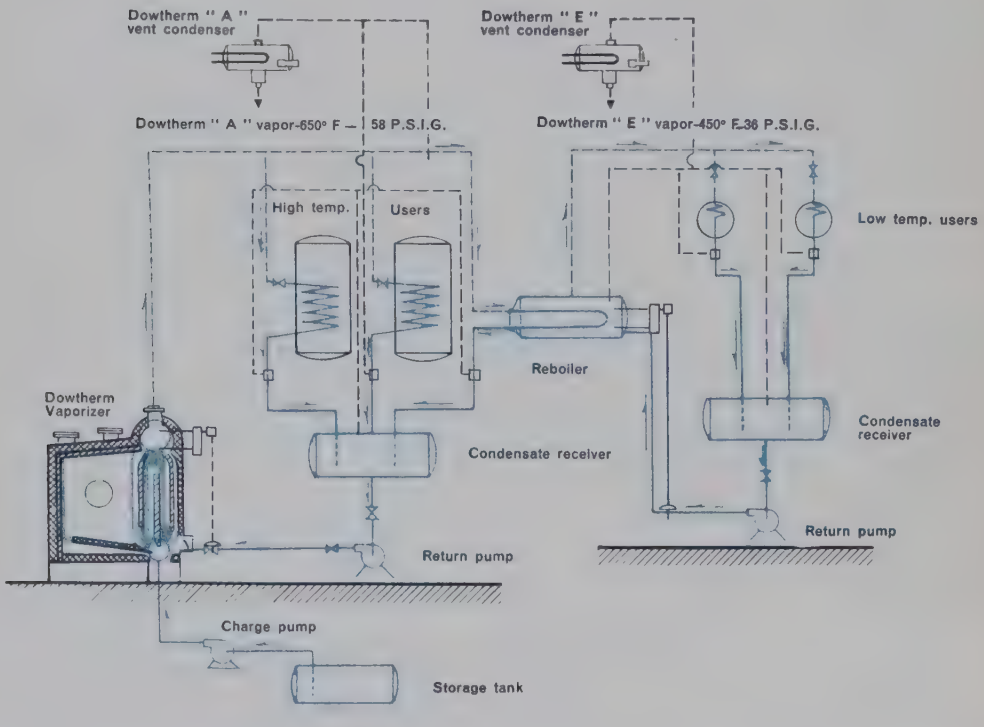

Fig. 7. Dual Medium Heating System with Dowtherm. (Figure supplied by Foster Wheeler Corporation.)

The many processes now using Dowtherm in the United States include the following : Distillation of fatty acids, vegetable oil processing, distillation of organic compounds of all kinds, production of dyestuffs, synthetic resins, nylon, synthetic rubber, hypersorption, esterification, heating and cooling of catalytic reaction chambers for catalyst regeneration, sulphuric acid concentration and indirect air heating. The last two examples are particularly interesting because the substances handled are not sensitive to heat.

Mercury

Mercury is not widely used as a heat transfer medium, but deserves greater attention. The Mission studied a large installation at the Sun Oil Co. where mercury vapour of about 420°C was used for heating the vacuum stills for lubricating oil. The unit consisted of three boilers, two of the old type with single drums and " porcupine " tubes and one new type fitted with bundles of three tubes of somewhat smaller diameter, twisted into coils. The latter type required an addition of magnesium and titanium, one part of each to about 30,000 parts of mercury, to ensure adequate wetting of the steel.

The plants were equipped with automatic mercury detectors for the flue gases and for the atmosphere in the boiler house. No difficulties had been experienced from mercury poisoning.

Boiling mercury is also used for cooling catalytic reactors for exothermic reactions such as the oxidation of naphthalene to phthalic anhydride.

Heat transfer salt (H.T.S.)

Considerable work has been done in the United States to develop the old method of using salt baths for heating. Attention has been concentrated on a mixture of nitrates and nitrites with a melting point of 142°C, called heat transfer salt. The obvious advantage of this medium is that it does not exert any measurable vapour pressure even at the highest feasible operating temperatures. It is used of temperatures ranging from its melting point of 142°C up to 450°C, where corrosion of mild steel becomes noticeable. By constructing the equipment of alloy steel the range can be extended to above 550°C.

The relatively high melting point of this medium makes it less suitable for batch processes with cycles of heating and cooling. All pipelines and tanks must be steam traced or jacketed to enable the plant to be started up after a shut-down. The hot H.T.S. can easily be circulated by pumps, preferably of the submerged type.

H.T.S. is used for cooling catalytic reactors and for heating reaction mixtures. A " packaged " experimental H.T.S. gas-fired heating unit with a capacity of 125,000 kcal/h (500,000 BTU/h) is available on the market in the United States.

High pressure steam and hot water

In the American chemical industry steam heating was stated to be used up to 180-200°C, corresponding to a pressure of about 9-15 kg/cm² (130-210 lb/sq.in.) gauge. In Europe there are chemical factories which distribute part of their steam from a central boiler house at 100 kg/cm² (1,400 lb/sq.in.) giving a temperature of about 310°C, but this is exceptional.

In Europe small steam generators directly connected to the equipment to be heated are used at certain points in the plant to give saturation temperatures up to about 360°C (190 kg/cm² or 2,700 lb/sq.in.). Hot water circulation is also common, and circulation of steam above the critical temperature (374°C) has been used successfully in Europe, 550°C having been reached by this method[1].

The " pebble heater "

A very interesting new method of heat transfer developed in the United States, but beginning to be used also in Europe, is the pebble heater. In this process a moving bed of ceramic material (small porcelain balls or pebbles) is used as a heat carrier. The method has been used for superheating steam for the dehydrogenation of ethyl benzene to styrene. One particular unit was able to heat about 7 tons/h of steam to 1,250°C (2,300°F). The pebble heater has also been used in the manufacture of carbon disulphide, and is being considered for other applications in the cracking industry and in gas manufacturing plants.

The pebble heater, which is shown diagramatically in figure 8, consists in principle of two separate chambers. In the upper heating chamber ceramic pebbles are brought to a high temperature by direct fire heating. The accumulated heat is moved by the downward flowing pebbles to the lower chamber where the endothermic reaction occurs. The cooled pebbles with deposits of carbon are then raised to the heating chamber, the carbon is burned off, and the pebbles are recycled again in the same way. This method overcomes the difficulty of all direct-fired stills, namely, that carbon or coke deposited on the tube walls of the heat exchangers greatly diminishes the rate of heat transfer.

It is important to note that the designs so far developed are limited to a maximum pressure of about 0.7 kg/cm² (10 lb/sq.in.) gauge.

Conclusions

Careful study of heat exchange problems has added considerably to the high efficiency of the American chemical industry.

The increased use of radiant heat transfer wherever possible has resulted in smaller and cheaper units with higher capacities.

The extensive use of organic and other heat transfer media has resulted in improved processing of heat-sensitive materials with closer temperature control.

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1. Cf. " Die Chemische Fabrik " vol. 7, 1934, page 421.

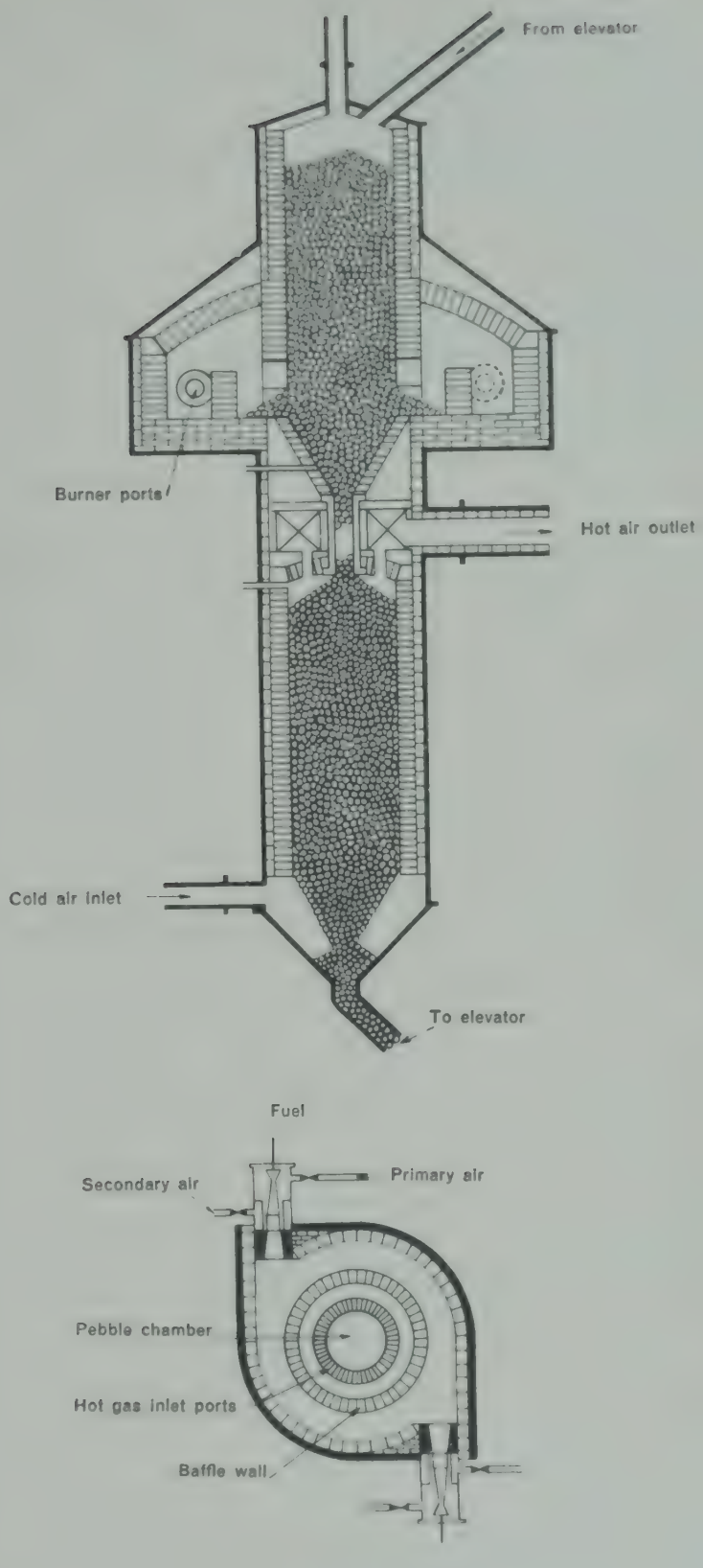

Fig. 8. Pebble Heater.

In the use of high pressure steam or hot water as heating media in the chemical industry Europe is ahead of America.

The pebble heater offers interesting possibilities for heating gases to high temperatures.

The exceptionally high heat transfer rates obtainable with surface boiling are likely to find important industrial applications.

Recommendation

By taking advantage of the advanced research work and the wide experience of industrial applications in the United States, European chemical plants might reduce heat losses in manufacturing operations and improve temperature control, thus ensuring smooth running and higher efficiency.

IX

MISCELLANEOUS EQUIPMENT FOR THE CHEMICAL INDUSTRIES

The theoretical basis for the unit operations of agitation, drying, filtration and centrifugation has not yet been sufficiently developed to exert a decisive influence on equipment design. There are therefore a large number of different types of equipment, based partly on purely practical considerations and partly on tradition within the different industries.

The lack of a strong theoretical approach makes it difficult to compare performance data obtained under different conditions and with different material, and as a result it is virtually impossible to draw conclusions of general validity about the relative merits of the different types of equipment seen. This is particularly true of agitation, because the fundamental concept of intensity of agitation has not yet been adequately defined.

Mixers and agitators

Agitation is of particular importance in heterogeneous chemical reactions such as dissolving a material in acid, chlorination of an organic compound or liquid, liquid extraction. An important modern example is the production of penicillin by mould fermentation. In this process oxygen is transferred from the air bubbling through the fermenter to the nutrient medium and subsequently together with the nutrients from the medium to the living micro-organism; at the same time carbon dioxide is transferred in the opposite direction.

The choice of agitator for a given purpose

Three basic types of agitators were studied by the Mission : the blade type, the turbine and the propeller. These types are well-known and extensively used in Europe.

Opinions differ widely both in the United States and in Europe with regard to the field of application of the different types. No evidence was presented to the Mission showing that an effect produced by one

type of agitator could not also be produced by another type, provided the mechanical design is sound and the rate of rotation so chosen that the energy absorbed per unit volume of the liquid is the same. It is also assumed that disturbing effects such as extremely high viscosity or the formation of deposits on heating surfaces are absent.

The statement that intensity of agitation depends only upon the energy input per unit volume of the liquid, and not upon the agitator design, obviously cannot be universally correct, but the data required for an objective assessment of the different types and for determining their range of optimum applicability still have to be collected.

Practical considerations are often decisive. Glass-covered agitators are produced by the Pfaudler Company in the shape of three-bladed curved impellors, mainly to suit their glass-lining process. It was stated that this standard type could be used for all agitation purposes to give results equal to those obtained with any other type. Different intensities of agitation are obtained by altering the speed of rotation. An adjustable baffle is provided which enables the intensity of agitation to be altered within a fairly narrow range without altering the agitator speed.

Special applications

During a visit to the General American Transportation Corporation the Mission was informed that turbo-agitators are almost exclusively used in the United States for the difficult heterogenous reactions involved in the production of penicillin and streptomycin by aerobic fermentation.

At the same firm the application of the turbo-agitator to flotation cells was outlined. The agitator is placed near the surface of the liquid and so arranged that the air required for flotation is sucked into the liquid by the action of the agitator. These cells therefore operate without any supply of compressed air.

Service supplied to customers

The firms manufacturing agitators distribute to their customers design charts which facilitate the selection of agitator speed and the determination of power consumption. These charts were considered in the United States to be an essential prerequisite for the successful sale of equipment of this type.

The information contained in these charts does not, however, enable the customer to draw any conclusions with regard to the intensity of agitation required for his particular heterogeneous reaction, nor to choose the optimum conditions of agitator speed and power consumption. Pilot plant work is essential in such cases, and the agitator manufacturers have anticipated this need and built comprehensive experimental stations where the customer's process can be carried out on a sufficiently large scale to provide adequate data for the design of the full-scale plant.

The use of standard types

The manufacturers of agitation equipment generally find it economical to concentrate on one or very few models and to maintain geometrical similarity between the different sizes. The required intensity of agitation is obtained by a proper choice of agitator speed and in some cases by the degree of baffling, although this interferes with the geometrical similarity.

Rotary filters

The rotary filter was first developed in the United States, but is now well-known and extensively used in Europe. Its advantages — continuous operation and small labour cost — are generally recognised and seem to be increasing steadily in importance, with the result that this type of filter is gradually being extended to materials with less favourable filtration properties.

Recent developments

The most important development in this field since the invention of the original Oliver filter is the introduction of the Bird-Young modification illustrated in figure 9. In this model the usual division of the periphery of the drum into segments each connected to a rotary valve is replaced by a sliding shoe connecting the discharge section of the drum to a supply of compressed air, the remainder of the periphery being connected to vacuum. The rotary valve is dispensed with and the construction greatly simplified. This is of particular importance where expensive acid-resisting materials of construction have to be used.

Since the periphery of the drum is divided into two sections only, a large one representing about 93 % of the filtering surface and connected to vacuum, and a small one of about 7 % connected to compressed air, the filtrate and the washing water cannot be collected separately.

The method of fixing the filter cloth to the drum shown in figure 9 is also novel and apparently of considerable merit. With the cloth more securely fixed greater air pressure can be used for the discharge of the filter cake. The cloth is more easily cleaned and blocking is less frequent. A much thinner cake can also be used which makes it easier to handle materials which are awkward to filter.

The Mission did not see the Bird-Young filter in operation and cannot therefore judge how far the apparent advantages of this type are actually realised in practice and how far the chemical industry in the United States prefers this filter to the more conventional models.

Continuous centrifugal settlers and classifiers

For truly continuous operation of centrifugal filters some device — usually a screw conveyor or a pusher — must be provided to ensure continuous removal of the filter cake. If the bowl of the centrifuge is

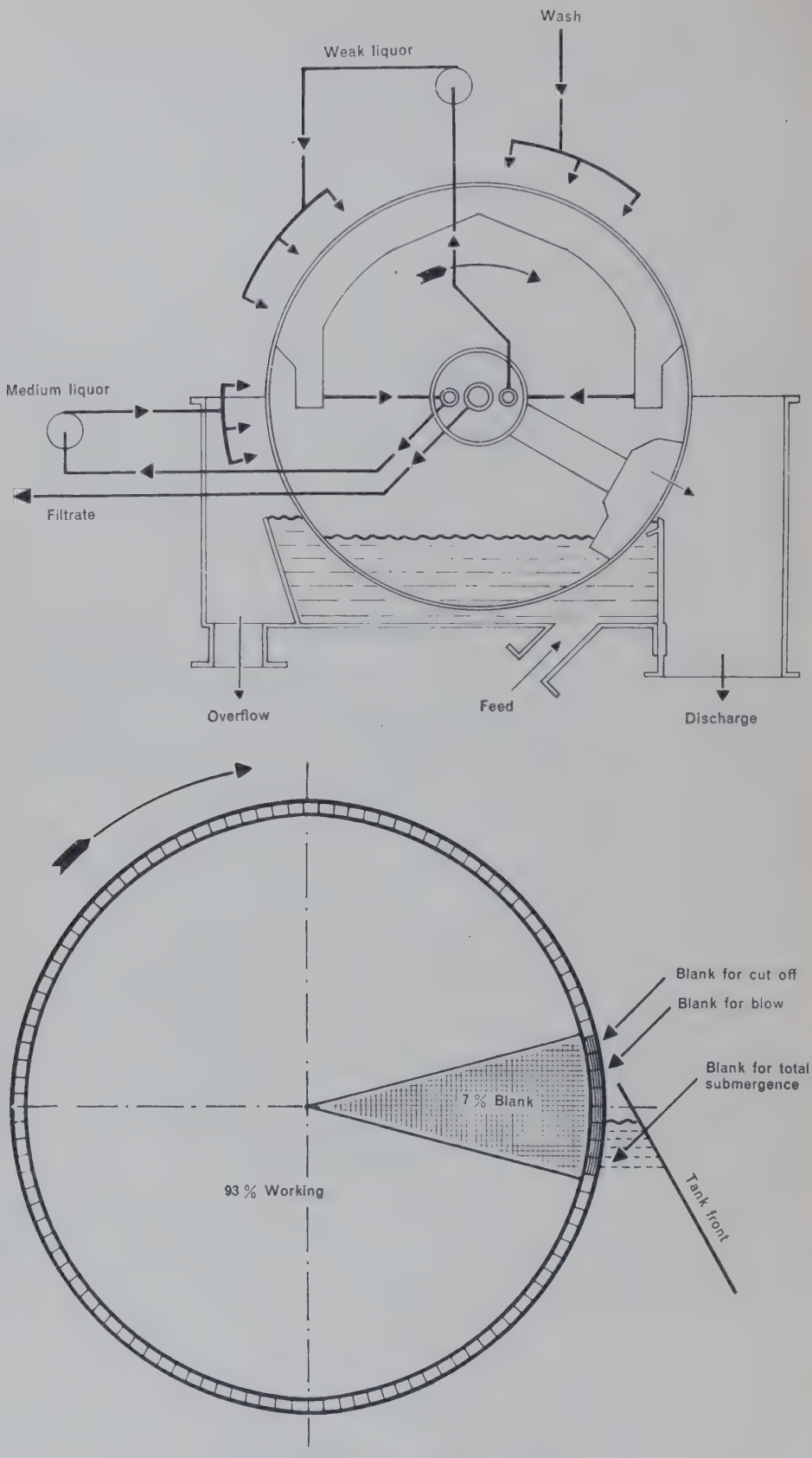

Fig. 9 a-9 b. Bird-Young Filter.

perforated and provided with a cloth or screen the process is one of true filtration, but if the bowl is solid the process is more properly termed centrifugal settling and draining or classification. The advantages of continuous operation can also largely be achieved by making the intermittent operation of ordinary centrifuges automatic.

Centrifugal filters of the intermittent, automatic type and of the plunger type are manufactured in Europe, but the centrifugal settler or classifier which the Mission had an opportunity to study at the Bird Machine Company is apparently not made in Europe, although it is probably well-known there.

Brief description of equipment

The centrifugal settler or classifier shown in figure 10 consists of a conical bowl which rotates at a speed of up to 1,400 r.p.m. The slurry to be treated is fed into the wide part of the bowl where the solid quickly settles as a result of the centrifugal force. A screw conveyor rotates inside the bowl at a slightly lower speed and moves the deposited solid out of the liquid to the narrow end of the cone where it is discharged. The liquid is discharged at the wide end through adjustable ports which permit the liquid level in the bowl to be fixed at the optimum position. The solid can be washed before it is discharged, but the washing water cannot be collected separately.

Since the machine is based on the principle of settling, it can easily be adapted to classification. By minor alterations to mechanical details the unit can be operated in such a way that only particles with a high settling velocity are removed as precipitates whereas those with a lower settling velocity remain suspended and leave the machine with the liquid.

The machines are available in 7 different sizes ranging from 0.15 to 60 tons/h of solids or 0.5 to 250 m^3/h of filtrate. Power requirements vary from 2 to 5 kWh per ton of processed solids.

Field of application

The machine was said to be widely used both for settling and for classification. It was claimed that the solids leaving the machines often have a lower water content than if the material had been filtered. This high degree of dehydration is due to the action of the centrifugal force on the cake after it has been lifted above the surface of the liquid, and before discharge.

Since the process is one of settling and not of filtration, there is a tendency for very fine particles to be carried out of the machine with the liquid. At the time of the visit tests with a suspension of an unspecified plastic were carried out. The solid material appeared to be surprisingly dry considering its nature, and the solution after filtration was clear, but not entirely free of precipitates.

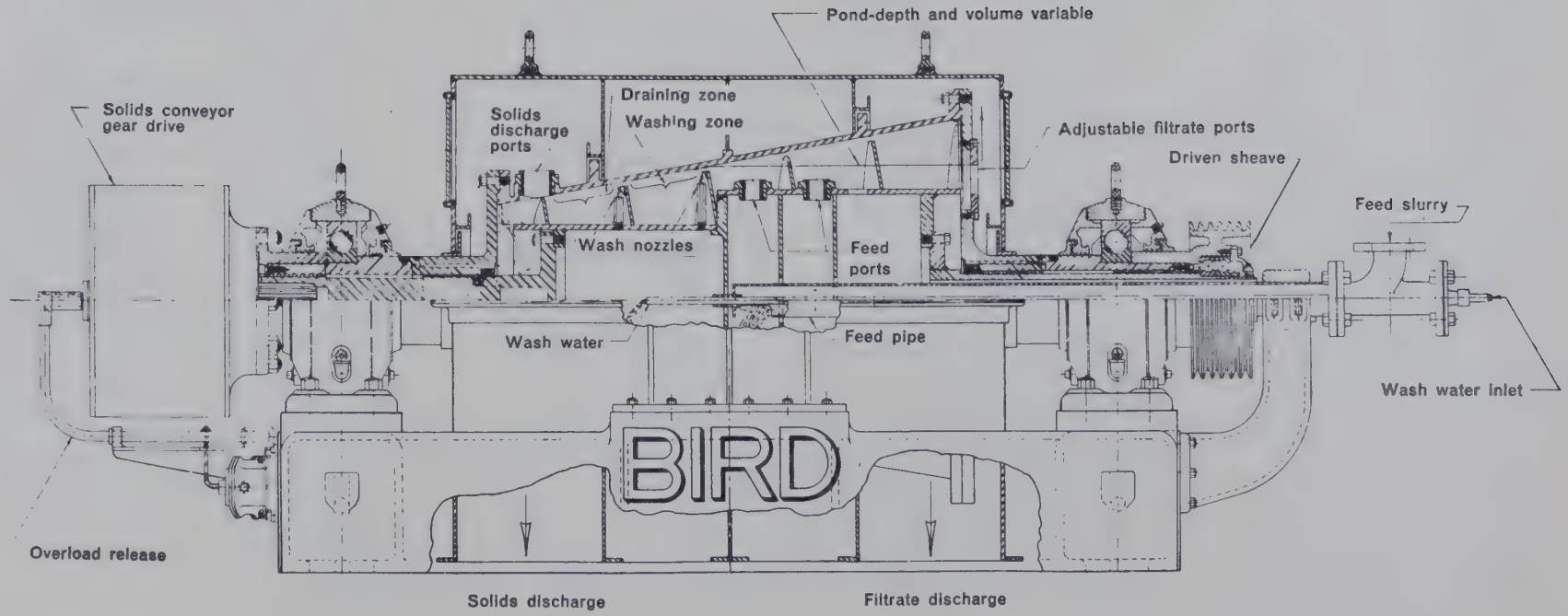

Fig. 10. Bird Centrifugal Settler.

It is to be expected that the action of the screw conveyor may tend to break up friable solids, and careful trials must precede full-scale application when such materials are to be handled by the machine.

A large number of successful applications of this technique were described to the Mission, including the handling of such materials as aluminium hydrate, iron ore, pectin, phenol, starch and vinyl resins.

Pilot plant equipment

During the visit to the Bird Machine Company, which manufactures both rotary filters and centrifugal settlers and classifiers, the Mission inspected a pilot plant designed mainly for carrying out filtration trials for customers. This pilot plant is exceptionally well equipped. The mixing tanks for the slurry can each handle 2.5 tons of material. Special areas with adequate ventilation are available where trials with volatile solvents or other dangerous materials can be carried out safely.

This is an excellent example of the services rendered by equipment manufacturers in the United States. The fundamental requirement is that performance must be guaranteed. If this cannot be done on the basis of calculations and experience, the manufacturer must provide facilities for trials on a sufficiently large scale to convince the customer of the suitability of the equipment. This is important to promote sales, but even more important as an insurance against expensive industrial failures.

Conclusions

1. The extensive service given by the equipment manufacturers to their customers greatly facilitates plant design and construction. The availability of design charts and comprehensive pilot plant facilities speeds up development and reduces the risk of costly failures.

2. There is a tendency for equipment manufacturers whenever possible to standardise a few well-developed, simple models, and to meet the different requirements by modifying the operating conditions rather than the mechanical design.

3. The most important recent development of the rotary filter is the mechanical simplification embodied in the Bird Young filter.

4. Continuous centrifugal settlers and classifiers can with advantage replace conventional filters in many applications.

Recommendations

These conclusions lead to the following recommendations :

1. European equipment manufacturers should consider extending their services to their customers, in particular by a more liberal provision of design information and pilot plant facilities.

2. European equipment manufacturers should attempt to reduce the number of types intended for similar purposes and thus reduce costs.

X

MATERIALS OF CONSTRUCTION FOR CHEMICAL EQUIPMENT

As far as the Mission was able to ascertain, American practice in the field of construction materials is very similar to European practice. This chapter gives a brief description of the more important aspects and is intended for readers to whom the subject is less familiar.

Stainless steel

Field of application

Stainless steel is much more widely used in the United States than in Europe; consumption in 1948 amounted to 500,000 tons or more than 3 kg per head of the population.

The Mission did not see any new application of stainless steel for highly corrosive conditions in the chemical industry, and American practice did not seem to differ from European either in this field or in applications at high temperatures under oxidising or other corrosive conditions. The greatest development seems to have taken place in the food processing industries, hospitals, etc., for hygienic and sanitary purposes. For example, in the dairy industry 97 % of the milk containers and 99 % of the pasteurisation equipment are made of stainless steel, while some 1 1/2 million stainless steel beer barrels are in use in the United States today. It is apparent that, for these purposes, stainless steel has replaced aluminium practically completely.

This tendency to expand into new fields is likely to be maintained in future by the development of new applications, e.g. in the television and building industries. By the introduction of a technique for joining a stainless alloy containing 27 % chromium to glass, it has become possible to make the large cathode ray vacuum tubes required for television largely of stainless steel. By keeping the use of glass down to a minimum, these tubes can be made less fragile and much safer. This application alone is expected to consume about 5,000 tons of alloy annually.

In the building industry stainless steel is beginning to find a number of applications where it was previously considered too expensive, e.g. roof gutters and external sheet metal work, particularly in coastal dis-

tricts. In one type of structure now being launched in the United States the conventional walls are replaced by metallic ones constructed of an outer 22 gauge stainless steel with fibre glass insulation between. The total wall thickness need not be more than 4-6 inches. These walls do not possess the heat capacity of conventional walls, and certain difficulties arising from this have not yet been solved satisfactorily. The new research building of the Alleghany Ludlum Steel Corporation and 3 skyscrapers in Pittsburgh are to be constructed in this way. If this method becomes general, the demand for stainless steel is expected to double.

Composition and corrosion resistance

The composition and corrosion resistance of stainless steel is doubtless well known to the reader and this section will be limited to a brief discussion of some types of chromium-nickel steels and their behaviour.

The most important types of stainless steel available in the United States are shown in Table 5.

Type 18-8, series 300 steels have good resistance to oxidation because of their high chromium content, oxidation resistance being, in fact, a function of chromium content. They can be employed in this type of duty up to temperatures of about 870°C. In the temperature range 400°C to 870°C, however, these steels are subject to the well-known carbide precipitation. This precipitation, which is the result of heating, takes the form of deposition of chromium carbides at the austenite grain boundaries. The effect of this precipitation is to render the grains in the region of the grain boundaries susceptible to corrosion attack. If, however, the alloys are not exposed to corrosion, then the precipitation may not be serious. Corrosion resulting from this type of precipitation in these steels has been widely referred to as intercrystalline corrosion.

The so-called stabilised steels are known as types 321 and 347. Type 321 is stabilised with titanium and type 347 with niobium (columbium). The latter is now more widely used in the United States than the former, but in Europe titanium stabilised steel has been used with success in a wide variety of conditions for many years. At the present time American manufacturers and users are seriously concerned about the shortage of niobium and steps are already being taken to change over from niobium stabilisation to titanium stabilisation.

There appears to be no difference in the tendency towards intergranular corrosion of titanium and niobium established steels, but niobium was claimed by some of the American experts visited to give steels which in a few cases show a higher general corrosion resistance. This was stated to be particularly true when the steels were tested in boiling nitric acid. It was pointed out that the extensive use of this test was largely responsible for the American preference for niobium, but the method does not appear to give a completely accurate picture of the relative merits of the two types.

TABLE 5. THE STAINLESS STEEL PRODUCED IN THE U.S.A.

Type	C	Mn	P	S	Si	Cr	Ni	Autres éléments
301	.08/.20	2.00	.04	.03	1.00	16.00/18.00	6.00/ 8.00	—
302	.08/.20	2.00	.04	.03	1.00	17.00/19.00	8.00/10.00	—
302 B	.08/.20	2.00	.04	.03	2.00/3.00	17.00/19.00	8.00/10.00	—
303	.15	2.00			1.00	17.00/19.00	8.00/10.00	PS Se_{min} 0.07- Zr Mo_{max} 0.60
304	.08	2.00	.04	.03	1.00	18.00/20.00	8.00/11.00	—
304 ELC	.03	2.00	.04	.03	1.00	18.00/20.00	8.00/11.00	—
305	.12	2.00	.04	.03	1.00	17.00/19.00	10.00/13.00	—
308	.08	2.00	.04	.03	1.00	19.00/21.00	10.00/12.00	—
309	.20	2.00	.04	.03	1.00	22.00/24.00	12.00/15.00	—
309 S	.08	2.00	.04	.03	1.00	22.00/26.00	12.00/16.00	—
310	.25	2.00	.04	.03	1.50	24.00/26.00	19.00/22.00	—
311	.25	2.00	.04	.03	1.00	19.00/21.00	24.00/26.00	—
314	.25	2.00	.04	0.3	1.50/3.00	23.00/26.00	19.00/22.00	—
316	.10	2.00	.04	.03	1.00	16.00/18.00	10.00/14.00	Mo 2,00/3.00
316 ELC	.03	2.00	.04	.03	1.00	16.00/18.00	10.00/14.00	Mo 2.00/3.00
317	.10	2.00	.04	.03	1.00	18.00/20.00	11.00/14.00	Mo 3.00/4.00
318	.08	2.00	.04	.03	1.00	17.00/19.00	13.00/15.00	Mo 2.00/3.00 Cb. 50/.90
321	.08	2.00	.04	.03	1.00	17.00/19.00	8.00/11.00	Ti_{min} 5 × C
325	.25	2.00	.04	0.3	1.50	7.00/10.00	19.00/23.00	Cu 1.50_{max}
329	.10	2.00	.04	.03	1.00	25.00/30.00	3.00/ 5.00	Mo 1.00/1.50
330	.25	2.00	.04	.03	1.00	14.00/16.00	33.00/36.00	—
347	.08	2.00	.04	.03	1.00	17.00/19.00	9.00/12.00	Cb_{min} 10 × C
403	.15	1.00	.04	.03	.50	11.50/13.00	—	—
405	.08	1.00	.04	.03	1.00	11.50/13.50	—	Al .10/ .30
406	.15	1.00	.04	.03	1.00	12.00/14.00	—	Al 3.50/4.50
410	.15	1.00	.04	.03	1.00	11.50/13.50	—	—
414	.15	1.00	.04	.03	1.00	11.50/13.50	1.25/2.50	—
416	.15	1.25	.04	.18/ 35	1.00	12.00/14.50	—	PS Se_{min} 0.07 Zr Mo_{max} 0.60
418	.15	1.00	.02	.02	1.00	12.00/14.00	—	W 2.5/3
420 over	.15	1.00	.04	.03	1.00	12.00/14.00	—	—
420 F	.15	1.25			1.00	12.00/14.00	—	PS Se_{min} 0.07 Zr Mo_{max} 0.60
430	.12	1.00	.04	.03	1.00	14.00/18.00	—	—
430 F	.12	1.25			1.00	14.00/18.00	—	PS Se_{min} 0.07 Zr Mo_{max} 0.60
431	.20	1.00	.04	.03	1.00	15.00/17.00	1.25/2.50	—
440 A	.60/.75	1.00	.04	.03	1.00	16.00/18.00	—	Mo 0,75
440 B	.75/.95	1.00	.04	.03	1.00	16.00/18.00	—	Mo 0,75
440 C	.95/1.20	1.00	.04	.03	1.00	16.00/18.00	—	Mo 0.75
440 F	.95/1.20	1.25			1.00	16.00/18.00	—	PS Se_{min} 0.07 Zr Mo_{max} 0.60
442	.25	1.00	.04	.03	1.00	18.00/23.00	—	—
443	.20	1.50	.04	.03	1.00	23.00/27.00	—	Cu .90/1.25
446	.35	1.00	.04	.03	1.00	18.00/23.00	—	N_{max} 0.25
501	.10	1.00	.04	.03	1.00	4.00/ 6.00	—	—
502	.10	1.00	.04	.03	1.00	4.00/ 6.00	—	—

One of the advantages of niobium is that steel stabilised with this element is more readily polished than titanium steel. While the latter takes on a good polish, the surface is somewhat marred by small comet-like defects associated with the titanium carbide inclusions.

The quantity of niobium required for stabilisation is about 8-10 times the carbon content, but if titanium is used, 5-6 times is sufficient.

The addition of molybdenum to chromium-nickel steels increases their resistance to specific corrosive media and, moreover, improves their mechanical properties at high temperature. Types 316 and 317 are in this category, the latter having a higher molybdenum and nickel content. It is emphasized that the molybdenum addition does not confer greater resistance to corrosion in all media — its use is confined to the handling of chlorides, sulphites, sulphuric acid and certain other specific chemicals. The addition of molybdenum has raised a special problem, since these steels, when heated in the temperature range 500-900°C, are susceptible to a transformation which may seriously impair corrosion resistance and ductibility. This is the formation of the sigma phase. Work is still going on both in the United States and in Europe on the best means of dealing with this new problem.

All the steels mentioned above have a basically austenitic structure, although the stabilised steels and the molybdenum steels also contain appreciable quantities of ferrite and are therefore ferromagnetic. Steels with ferritic and martensitic structures are also available and may be either straight chromium steels insufficient to confer an austenitic structure. Recently steels have been produced in the United States with a substantially austenitic structure but capable of heat treatment by precipitation hardening.

Welding of stainless steel

Stainless steels can be welded by all methods used on normal carbon steels, except forging. The most important difficulty is the carbide precipitation mentioned above, which can lead to intergranular corrosion. Two methods of reducing the danger of carbide precipitation have already been tried : the use of stabilisers, and a carbon content below 0.03 %, provided that the time of heating is reasonably short.

A third method is to re-dissolve the carbides by heating the welded equipment to 1,035°C or higher, followed by rapid cooling through the critical interval. This method is extensively used both in America and in Europe.

A fourth method, which is used considerably in the United States, but, as far as can be ascertained, not in Europe, is to reduce the time of heating during welding to such an extent that carbide precipitation, even for unstabilised steels with above 0.03 % carbon, is insufficient to cause susceptibility to intergranular attack. Heating times can be reduced by water cooling, the welding in some cases being done actually under water. This method uses the cheapest type of stainless steel and

avoids the expense of heat treatment, but the welding equipment is more elaborate and expensive. The main disadvantage is that repairs and alterations to equipment manufactured by this method cannot be effected by welding, except by firms possessing the necessary equipment. This is an important point for purcharsers of stainless steel equipment from the United States to bear in mind.

It is generally realised that the process of metal arc welding involves the loss of some of the easily oxidised constituents of the metal. A small quantity of chromium is lost in this manner and the loss of titanium is so great that electrodes cannot be stabilised with this element. For this reason it has been general practice for several years, both in the United States and in Europe, to use electrodes stabilised with niobium. Such electrodes can be used with perfect satisfaction in the welding of stainless steel stabilised with titanium.

Electric arc welding is most generally used for stainless steel in the United States as well as in Europe. Direct current is mainly used and the article to be welded is connected to the negative pole of the rectifier.

In recent years the shielded arc welding method has also gained a wide application in the United States as well as in Europe. Helium or argon has proved particularly suitable. The current is carried by a wolfram electrode which is surrounded by a neutral atmosphere of argon or helium to prevent oxidation and contamination of the weld. The wolfram electrode is not consumed during the process, the stainless steel sheets being simply fused together. Argon and helium are equally suitable, but considerations of price have led to the exclusive use of argon for stainless steel. It is interesting to note that for copper helium is essential. The shielded arc method is used for plates up to 3 mm. thick, and offers the great advantage of practically eliminating the need for subsequent polishing of the welds.

Another welding technique which is used in the United States is the well-known atomic hydrogen process, details of which are available in the technical literature. This process is not used for general welding, being confined to the welding of a thin section to a much thicker one. This technique seems to have been largely replaced by the shielded arc method, but is used for instance for tool steel.

Resistance welding is particularly suitable for stainless steels because they have an electrical resistance about six times that of ordinary carbon steel. The metal is quickly heated by the passage of current, and the heat is confined to a limited area. For these reasons the danger of carbide precipitations is reduced, although not eliminated. Resistance welding is used to a certain extent in the United States as well as in Europe.

Oxy-acetylene welding of stainless steel is still used in the United States, mainly for thicknesses up to 1.25 mm. and in certain cases with great success. Generally, however, electric arc welding is preferred.

Apart from the heat treatment to dissolve precipitated carbides, stress relieving after welding is widely practised to avoid stress corrosion during subsequent service.

Stainless clad steel

In order to reduce the cost of stainless steel pressure vessels it is common practice in the United States as well as in Europe to use carbon steel to take up most of the stresses and to provide a lining of stainless steel to give protection against corrosion. The lining can be spot welded to the carbon steel, but this method is only suitable in very mild corrosive conditions. More satisfactory are the so-called stainless clad steels made by melting and rolling the two layers together. Owing to difficulties in manufacture it is unusual in the United States to work with linings thinner than about 20 % of the total wall thickness. Even so this material was not recommended for other than mild corrosive conditions where the main object is to avoid contamination of the products with iron. The stainless clad steels were not considered economical for wall thicknesses below 1/2 inch.

Construction of pressure vessels by the " layer method "

In two firms manufacturing chemical plant the Mission had the opportunity of studying the construction of pressure vessels by the layer method. This type of vessel consists of an inner shell, which takes up the longitudinal stresses, enveloped in a number of layers of welded sheets designed to take up the tangential stresses.

Comparative tests on vessels constructed by the layers method and by the solid wall method show that the former usually give 100 % efficiency as against about 60 % for the latter. The layer method therefore saves a considerable amount of material. The method was stated to be economically advantageous at pressures above 35-175 kg/cm^2, depending upon the diameter of the vessels.

The layer method of construction for pressure vessels is well known to some European countries and has been applied there for a long time.

Aluminium

Field of application

The great development of stainless steels during the last twenty years has by no means reduced the interest in aluminium and its alloys in the United States. Such characteristics as good thermal conductivity, light weight, resistance to corrosion, non-sparking tendencies, lack of possible discolouration of product and lack of toxicity to micro-organisms are some of the qualities which attract designers to aluminium. There is little doubt, however, that for some applications the greater hardness, rigidity and heat resistance of stainless steels has tipped the balance in their favour, in spite of the lower price of aluminium. This tendency is noticeable both in America and in Europe.

The application of aluminium in the chemical industry in the United States does not generally seem to be in advance of European practice. The interest in aluminium alloys for the construction of pressure vessels

Table 6. COMPOSITION OF COMMERCIAL ALUMINIUM AND SOME OF ITS ALLOYS

ALLOY	ALUMINIUM	COPPER	IRON	SILICON	MANGANESE	MAGNESIUM	ZINC	CHROMIUM	TITANIUM	OTHER ELEMENTS PER CENT	
	PER CENT	PER CENT	PER CENT	PER CENT	PER CENT	PER CENT	PER CENT	PER CENT	PER CENT	EACH	TOTAL
A3	99.6 min (d)	0.05	(a)	(a)	—	—	—	—	—	0.05	0.15
A2	99.0 min (d)	0.20	(a)	(b)	0.10	—	0.10	—	—	0.05	0.15
M1	remainder	0.20	0.70	0.60	1.0 to 1.5	—	0.10	—	—	0.05	0.15
GR1	remainder	0.10	(c)	(c)	0.10	2.2 to 2.8	0.10	0.15 to 0.35	—	0.05	0.15
GS21	remainder	0.15 to 0.40	0.70	0.40 to 0.80	0.15	0.80 to 1.2	0.10	0.15 to 0.35	0.15	0.05	0.15

(a) Iron plus silicon must not exceed 0.4 per cent.
(b) Iron plus silicon must not exceed 1.0 per cent.
(c) Iron plus silicon must not exceed 0.45 per cent.
(d) By difference.

and instrument tubing seems to be greater than in Europe. On the other hand, Europe appears to be leading with regard to the purity of the aluminium. The first hydrogen peroxide plant to be built in America after the war was constructed of aluminium imported from Europe. The required quality is now produced also in America.

The applications of aluminium in industries dealing with such products as concentrated nitric acid, acetic and fatty acids as well as hydrogen peroxide and formaldehyde are well known and will not be dealt with in this Report.

Aluminium is known to be resistant to sulphur compounds and is therefore widely used in the oil industry for tanks and equipment handling sulphur hydrocarbons. Sulphur eliminating columns were stated to be fitted with bubble caps of an aluminium silicon alloy.

Composition and properties of aluminium and its alloys

The mechanical strength of pure aluminium is insufficient for many purposes, particularly for the design of pressure vessels, and alloys with more favourable mechanical characteristics have been developed. The most important alloys used in the United States are listed in Table 6. and their mechanical properties in Table 7. Alloys A 2 and M 1 were

Table 7. Mechanical properties of aluminium and some of its alloys

Alloy	Temper	Thickness	Tensile strength		Yield strength		Elongation in 2″ per cent
			p.s.i.	*Kg/mm²*	*p.s.i.*	*Kg/mm²*	
A3	Annealed	.051 to 3.000	9,500	6.7	3,500	2.4	25
A2	Annealed	.051 to .249	11,000	7.7	4,000	2.8	30
		.250 to 3.000	11,000	7.7	4,000	2.8	28
M1	Annealed	.051 to .249	14,000	9.8	5,000	3.5	25
		.250 to 3.000	14,000	9.8	5,000	3.5	23
GR1	Annealed	.051 to .249	25,000	17.5	10,000	7.2	20
		.250 to 2.000	25,000	17.6	10,000	7.2	18
		2.001 to 3.000	23,000	16.2	9,500	6.7	18
GS21 Alcoa 615-T4	Heat treated	.051 to .249	30,000	21.1	16,000	11.2	16
		.250 to 1.000	30,000	21.1	16,000	11.2	16
		.001 to 3.000	30,000	21.1	16,000	11.2	16
GS21 Alcoa 615-T6	Heat treated and aged	.051 to .500	42,000	29.5	35,000	24.6	10
		.051 to 1.000	42,000	29.5	35,000	24.6	9
		1,001 to 2.000	42,000	29.5	35,000	24.6	8
		2,001 to 3.000	42,000	29.5	35,000	24.6	6

stated to be preferred for most purposes in the chemical industry, provided they have a satisfactory corrosion resistance under the conditions of employment.

At high temperatures the mechanical strength of the metal and its alloys decreases rapidly, and pressure vessels for use above 200°C (400°F) should not be constructed of such materials unless an outer shell of steel is used to take up the stresses. Even at temperatures below 200°C the strength is considerably lower than at room temperature (*fig.* 11).

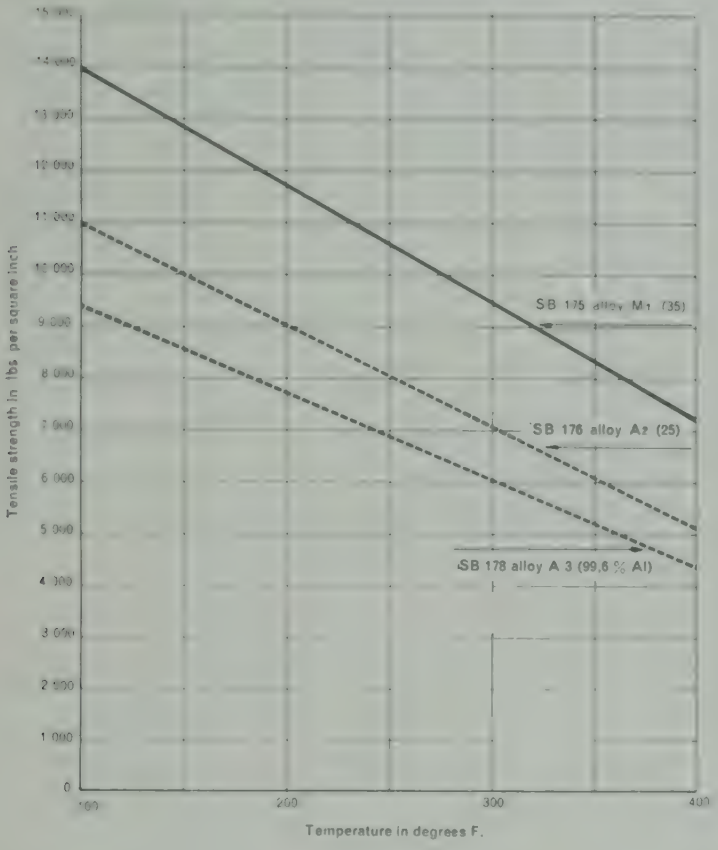

Fig. 11. Tensile Strength of Aluminium Alloys as Function of Temperature.

With decreasing temperatures, however, the mechanical properties of aluminium improve (*Table* 8), and it does not become brittle even at the temperatures encountered in air separation plants. Both in America and in Europe it has therefore found a wide application in modern tonnage oxygen plants, particularly for the construction of towers and reversing heat exchangers.

Corrosion and protection

Difficulties due to mercury contamination were stated to be increasing in the United States, and a high proportion of failures could be traced to this source. The use of nitric acid and bichromate was

recommended for removing mercury, but there is, unfortunately, no way of knowing if the treatment has removed all the mercury before the equipment is put into service again.

It is well known that aluminium has a very low capacity for forming solid solutions, and that its alloys are of the two-phase type and consequently liable to electrochemical corrosion. Aluminium of high purity is therefore most resistant, whereas the alloys generally, but not always, are more susceptible to chemical attack. The highest purity obtainable commercially in the United States was stated to be 99.85 % Al, whereas the usual " pure " aluminium (A 3) contains about 99.6 % Al.

It is well known that aluminium alloys can be protected against chemical attack either by covering them with a sheet of pure metal more resistant to corrosion or with an alloy containing about 1 % zinc which will provide galvanic protection. Both methods have been used in Europe, the former extensively and the latter mainly to protect aluminium copper alloys against hard waters. It is important to note that galvanic protection must be applied with care, particularly when the pH is rather high, because an increase in temperature to about 70°C might reverse the polarity between the aluminium and the zinc. The method must therefore be used circumspectly for condenser tubes, cooling jackets and similar items.

It was stated that anodising was not used in the United States for chemical equipment. Etching treatments are, however, often carried out on items like beer barrels, while there is a special chemical cleaning treatment for hydrogen peroxide containers.

Welding

The welding of aluminium is usually carried out, as in Europe, with an oxy-acetylene or oxy-hydrogen torch. This process requires a flux which must be thoroughly removed afterwards in order to avoid corrosion in the presence of moisture. It was stated that aluminium plates up to about 1 1/8 inches thick could be welded satisfactorily by this method.

Table 8. MECHANICAL PROPERTIES OF ALUMINIUM ALLOYS AT DIFFERENT TEMPERATURES

TEMPERATURE OF		TYPICAL TENSILE STRENGTH		TYPICAL YIELD STRENGTH		ELONGATION IN 4 D[1] PER CENT
F°	C°	p.s.i.	KG/mm²	p.s.i.	KG/mm²	
75	24	16,000	11.2	6,000	4.2	40
0	— 18	17,000	11.9	6,000	4.9	41
— 112	— 80	19,500	13.7	7,000	5.1	42
— 320	— 195	33,000	23.2	8,500	5.9	46

1. Elongation values are for round specimens with gauge length equal to four times the diameter.

The introduction of the shielded arc method has recently made it possible to weld much thicker plates. This method requires no flux, it can be performed in all positions and minimises the softening of the metal near the welds. It is, however, expensive, and has therefore not replaced conventional welding methods for aluminium to any great extent either in the United States or in Europe.

Design and construction

Although steam-jacketed kettles made of aluminium or its alloys have been used in the food processing industry in the United States since about 1908, the design of pressure vessels is not yet in an entirely satisfactory state. Difficulties have been experienced because the design codes developed for steel were applied to aluminium without giving proper consideration to the different nature of the two metals. Some failures have occurred, and more work is required before the codes for aluminium pressure vessels can be finalised. This has not, however, prevented a widespread use of aluminium alloys for the construction of pressure vessels in the United States. For further information on A.S.M.E. codes, see " Aluminium alloy vessels " by E. G. Kort (Trans. A.S.M.E. December 1948). This paper cites examples of pressure vessels designed for working pressures up to 3.2 kg cm^2 (45 lb/sq.in).

As already stated, it must be remembered that the mechanical strength of aluminium and its alloys decreases rapidly as the temperature increases. In these circumstances the design should be based on the strength of the annealed metal, since some local softening is bound to occur as a result of welding.

Enamelled (glass-lined) equipment[1]

Field of application

The unique general corrosion resistance of glass has resulted in the widespread use of enamelled equipment both in the United States and in Europe. Its inherent weakness of sensitivity to mechanical and thermal shock is more than offset by chemical resistance to practically all reagents except alkalis, hydrofluoric and strong phosphoric acids. Even in cases where satisfactory alternative construction materials are available, enamel-lined steel was often stated to be preferred on economic grounds. For vessels larger than about 0.2 m^3 capacity enamel-lined steel was stated to be cheaper than austenitic stainless steel. Large numbers of enamel-lined storage tanks of 38 m^3 capacity are in service in breweries in the United States. In severe corrosive conditions their capacity does not exceed 13 m^3 and in exceptionnally severe conditions is limited to 7.5 m^3. Enamel-lined vessels are also used to a large extent for the preparation of fruit juices, in dairies and in the dye industry.

1. The American term glass-lining is equivalent to the European term enamelling.

Big silage-towers for storing harvests are made of enamelled sheets, screwed together with enamelled bolts, and are said to be absolutely gas-tight. Silage spoilage, which ranges up to 25 % in conventional units, is eliminated because oxygen is excluded.

Enamel-lined equipment is normally designed for pressures up to 8.8kg/cm² (125 lb/sq.in.) and in extreme cases up to 105 kg/cm² (1,500 lbs/sq.in.). The plate thickness is generally limited to 1 in., but 2 1/2 in. have been used; the highest quality lining permits operation at 260°C (500°F) but by taking special precautions some users have operated their vessels successfully considerably above that temperature.

Manufacture of enamel linings

The constituents, which may include, among others, silica, with fluxes such as feldspar, fluorspar and borax, are sintered at 1,250°C; the mixture is then chilled with cold water and ground. The " frit " is mixed with clay and ground again to a fineness of 200 mesh. The low temperature enamel used solely to prevent contamination contains a low proportion of silica and a high proportion of fluxes, whereas the acid-resisting enamels contain more silica.

The coating is made by spraying a suspension of the finely ground material on to the surface. For highly corrosion-resistant enamel several coatings are applied in order to ensure freedom from pinholes. Enamel intended primarily to prevent contamination need not be entirely free from pinholes.

Firing is carried out in furnaces heated by gas, and takes 20 to 30 minutes. For large vessels several huge furnaces, 15 m. long and 5 m. high, were seen in operation. A higher firing temperature is required if the enamel is to resist acid than if it is merely to prevent contamination.

Heat transfer to enamel-lined vessels

Coils for heating and cooling cannot be enamelled satisfactorily and the use of coils in enamel-lined vessels is avoided whenever possible.

If coils have to be used they are usually made of Hastelloy, and welded by the Heliarc method, the coils being filled with helium during the welding operation.

The vessels are equipped with jackets for heating and cooling the charges. The heat transfer coefficients obtained with liquid heat transfer media in jackets are notoriously very low, but can be substantially improved by introducing the cooling medium at high speed tangentially into the jacket through nozzles, if necessary by means of auxiliary pumps.

Good agitation is an essential prerequisite for good heat transfer. A standard type agitator and adjustable baffles were used in all cases, the different degrees of turbulence being obtained by varying the agitator speed.

Stuffing boxes

These present a very difficult problem. In order to prevent the enamel covering on the shaft from wearing out in the stuffing box, the shaft is provided with a replaceable sleeve of stainless steel or Hastelloy. It is essential to provide a second bearing in the stuffing box to prevent whip, and the lantern ring is designed to give this necessary support to the shaft. In extreme conditions forced lubrication is applied and the stuffing box is provided with water-cooling.

Gaskets

Enamelled flanges cannot be as smooth and even as machined flanges; the gaskets must therefore be resilient and the flanges very strong to enable a high tightening pressure to be applied without distortion occurring. Teflon is widely used as gasket material, but its physical and mechanical properties will not permit it to be used unaided, and the so-called " shielded " gasket has been developed. It consists of a Teflon shield to give chemical resistance, an inserted core of compressed asbestos to provide the necessary strength and asbestos millboard on each side of the core to give resilience. This design was stated to have given excellent service over very long periods.

Design difficulties

The design of enamelled equipment, particularly of the acid-resisting type, is most important because the enamel has a low tensile strength and is easily damaged by mechanical shock. Plate thickness, flange dimensions, etc. must be chosen to give little deformation under working conditions. Sharp corners must be avoided.

Maintenance and repair

The lining should be inspected at frequent intervals, and in case of damage, the vessel should immediately be taken out of service for repair. The lining can be tested with a spark coil but voltages above 20,000 should not be used, as damage to the lining might result.

There is no repair material available which has the same general corrosion resistance as the original lining. Smaller defects are repaired by filling with gold, ceramic-material, acid-resisting cement or by plugging with tantalum. Larger defects are repaired with tantalum shields fitted with teflon gaskets. These methods of repair are also used in Europe. It is important to note that tantalum is not resistant to free sulphur-trioxide.

Hydrochloric acid should not be used to remove scale from the jackets of glass-lined vessels because some of the hydrogen evolved was stated to diffuse to the enamelled surface and crack the lining. Fairly good results were obtained with a weak solution of sodium hypochlorite.

Development work

There are two major objectives for development work in this field: to improve the resistance to thermal shock and to alkalis. The relatively poor resistance of enamel linings to thermal shock is due to the poor tensile strength and elasticity of the glass. Tensile stresses must therefore be avoided, preferably by giving the lining in the finished product a certain compressive pre-stress. This can be achieved by using linings with a lower coefficient of thermal expansion than the metal. During cooling the lining will then automatically come under compression. It was stated that experiments had confirmed the superiority of the pre-stressed linings over those which have the same coefficient of thermal expansion as the underlying metal. By using a suitable combination of ground coat and main coat it has been possible to produce an enamel which can be heated to about 480°C (900°F) and then dropped into cold water with very little chipping.

It is well known that the low tensile strength of glass is caused by very fine, inevitable surface cracks which are associated with the brittleness of the glass. Work is therefore also directed towards the more distant objective of developing enamels with better tensile strength and elasticity.

Glass has a very high compressive strength and it was stated that to break the enamel lining under compression the steel would have to be stressed above its elastic limit.

It has recently become important to develop an enamel with reasonable resistance to dilute alkalis. For most purposes it is easy to find excellent alternative materials of construction for alkaline solutions, but in the production of polymers by emulsion polymerisation it has been found that the polymers stick to all metals, but not to glass. The glass, however, is attacked by the dilute alkaline solutions and the polymers stick to the etched surface. This work was stated so far to have yielded enamel linings which will permit neutralisation of acids with alkalis without noticeable attack.

All new developments of enamel linings must satisfy the technological requirement that the necessary firing temperature must not exceed about 870°C (1,600°F) for the ground coat and 810°C (1,500°F) for the main coat. At a higher temperature serious deformation takes place. Lithium salts are usually used to lower the melting point of the enamel.

Plastics

General

The Mission had only a limited opportunity to study the use of plastics as materials of construction for chemical equipment. This report will consider briefly two polymerised halogenated ethylenes, both further developments of polyethylene, which were discovered and developed in Europe, and extensively used there.

Teflon

Teflon (polytetrafluorethylene) which is manufactured by Du Pont has a high resistance to chemical action. No effect has been observed after prolonged exposure to fuming and concentrated nitric acid, aqua regia and other strong oxidising agents, to concentrated sulphuric, hydrofluoric and hydrochloric acids, or to strong caustic. It can stand temperatures up to about 200°C continuously.

From the chemical point of view Teflon can be considered as the best packing material now available, though it is not a cure for all troubles, because it is plastic and has a tendency to flow under pressure.

The price of Teflon is about $ 10 per lb. It is produced in sheets, rods, tubes and for research work, in tapes of 0.002 in. to 0.06 in. thickness.

The manufacture of a polymer of similar composition, called Fluon, has already been taken up in Europe, but is not yet generally available.

Kel-F

Recently the M. W. Kellogg Co. developed a similar material named Kel-F. Chemically it is a polymer of trifluoromonochlorethylene, an exceptionally stable, high temperature, non-inflammable, thermoplastic. It has satisfactory properties over a temperature range of about 400°C, viz. from —196°C (liquid nitrogen) to 190°C. Its " no strength temperature " (N.S.T.) is about 315°C.

A comparison of properties shows that Teflon and Kel-F are almost equivalent. Both are used as a coating material for steel. Emulsions of these polymers in aromatics can be cold sprayed on the metal, the solvent evaporated and the dry layer of polymer fused, the melting-point of the powder being about 350°.

The coating can be produced in different colours by mixing the powder with inorganic dyes.

Conclusions

1. As regards materials of construction for chemical equipment, the level of technique seems to be much the same in the United States and in Europe.

2. The use of stainless steel in the United States is expanding rapidly particularly in the food processing and pharmaceutical industries.

3. Welding methods are generally similar to those used in Europe with one exception : to a considerable extent ordinary unstabilised stainless steel is welded with water cooling so as to reduce the heating time to the point of rendering carbide precipitation negligible.

4. In the field of aluminium considerable interest appears to be shown in the manufacture of pressure vessels and instrument tubing.

5. Manufacture of enamelled equipment of the usual grades appears

to be well advanced, and the leading American firms seem to be equipped to handle larger vessels than the European manufacturers. The use of Teflon shielded gaskets is noteworthy.

6. Teflon and Kel-F are recognised as the most important recent American contributions in the field of materials of construction for chemical equipment. It is important to note that a material similar to Teflon is already in production in Europe.

Recommendations

The attention of the European chemical industry and equipment manufacturers should be drawn to developments in the United States, particularly with regard to welding of stainless steel with water cooling, use of layer vessels for high pressure, aluminium pressure vessels and instrument tubing, and Teflon shielded gaskets.

XI

TRANSPORT AND STORAGE OF CHEMICAL PRODUCTS[1]

With the growth of the chemical industry in the United States the quantities of raw materials and chemical products to be transported are steadily increasing. Shipment in bulk has become feasible for an increasing number of products and has reduced transport and packing costs and prices generally. Liquid products which must be shipped in returnable containers, e.g. iron drums or demijohns for smaller lots, are particularly affected but so are powdery materials like cement. Bulk shipments have also undoubtedly contributed to the growing specialisation in the field of chemical manufacturing by making it possible to ship intermediate products between the different plants at low cost. Lastly, reduced transport costs have promoted centralisation by increasing the economical size of the manufacturing units, as decreasing distribution costs mean that the units can serve larger areas.

The development which has taken place in the United States in the field of transport is clearly illustrated by the increase in the number of products shipped in bulk, which has risen from about 30 at the end of the first world war to about 500 today. This trend is also evident in Europe, but to a lesser degree.

In the United States the car-leasing companies play an important part in the organisation of bulk transport by providing and maintaining fleets of special cars for practically any purpose.

An essential condition for bulk shipments is that the manufacturers as well as the consumers should have sufficient storage space to be able to load and receive bulk shipments. The Mission therefore studied some aspects of this question, which is very important for liquids particularly those which have a considerable vapour pressure at ordinary temperatures.

The subject of rail transport has been specially studied by O.E.E.C. Mission No. 14, " Railroads ", which left for the United States in September 1950. Reference is made to the Report of this Mission.

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1. This subject has been treated at some length at the request of one country which is specially interested in it.

Liquids

In the United States the tank car is undoubtedly the most commonly used means of transport for liquids. It is designed as a horizontal cylinder, sometimes divided into compartments, each provided with a dome. The regulations issued by the Interstate Commerce Commission require tank cars to be fitted with safety discs, at least two for cars of over 25.17 m^3 capacity. In order to reduce the non-revenue load, i. e. weight of equipment per ton of product transported, efforts are made to increase the capacity and to use low alloyed high tensile steels as well as aluminium alloys. Modern methods of welding are also important in this respect. The capacities of some American tank cars are shown in Table 9, the two smallest sizes being by far the most common.

Table 9. SOME TYPICAL AMERICAN TANK CARS

CAPACITY GALLONS	M^3	LOAD KG	LIGHT WEIGHT KG	RATIO OF LOAD TO LIGHT WEIGHT
8,000	30.28	36,288	19,051	1.90
10,000	37.85	45,360	22,680	2.00
12,000	45.42	54,432		
15,000	56.78	68,040		
20,000	75.70	90,720	39,917	2.27

It is apparent from Table 9 that American tank cars are considerably larger than European cars.

Linings of such materials as plastics, rubber, and even glass and enamel are used to protect the load from contamination as well as to prevent corrosion of the tank. For the lining of tanks which are to carry foodstuffs polyvinyl plastics are especially suitable. It is, however, very important to choose the fillers and plasticisers with great care to avoid contamination of the foodstuffs. Titanium dioxide has proved a very good filler for such purposes.

Table 10 gives a brief summary of the materials used for the construction of tanks intended for the transport of liquid chemical products.

In Europe most of these products are also carried in tank cars and aluminium is often preferred for concentrated nitric acid. An example of a modern American tank car is shown in figure 38, p. 210.

Products which solidify easily

Many chemical products which are solid at ordinary temperature but which will liquefy on a moderate rise in temperature can obviously be transported with advantage in tank cars. The cars are either insulat-

Table 10. List of construction materials for tanks transporting liquid chemical products

Ordinary steel	Crude oil
	Petrol
	Fuel oils
	Lubricating oils
	Asphalt
	Caustic soda
	Sulphuric acid, concentrated
	Coal tar oils
	Solvents
	Technical oils and fats
Ordinary steel, rubber-lined	Hydrochloric acid
	Phosphoric acid
	Sulphate of alumina
	Formaldehyde
Ordinary steel, plastic-lined	Sulphuric acid, diluted
	Grain alcohol
	Wine
	Foodstuffs
Ordinary steel, glass-lined	Calcium hypochlorite
	Milk
	Sugar, liquid
Ordinary steel, nickel-clad	Caustic soda, iron-free
Stainless steel	Nitric acid
Aluminium	Acetic acid, glacial
	Acetic anhydride
	Glycerine, chemically pure
	Hydrogen peroxide
	Nylon salt solution

ed or fitted with steam coils. Cork, fibre glass, and plastic foam are mostly used as insulating materials. The plastic foam is blown directly on the tank. The insulation is usually 50-100 mm. thick, but in exceptional cases may amount to 300 mm.; it is protected with thin metal plates.

To take an example, 73 % caustic soda, which solidifies at 62°C, can be loaded as a hot liquid into an insulated tank and will still be liquid even after 20 days transport, which shows the efficiency of the insulation. Sulphur which solidifies at 113°C must be transported in tank cars fitted with steam coils. The sulphur is loaded in a molten condition, but solidifies and must be remelted by the recipient.

Transport of gases and liquid products under pressure

Liquefied gases and volatile products are also transported in tank cars of the usual design, but with tanks tested at pressures up to 42 kg cm² gauge. At pressures beyond 21 kg cm² the tanks are lap-welded and

usually heavily insulated to prevent excessive pressures from developing on hot days. Tank cars of this type carry chlorine, sulphur dioxide, anhydrous ammonia, ethylene oxide, propane, butane and other volatile petroleum products. For chlorine another type is also used, consisting of the usual flat car with a number of lap-welded steel tanks which can be removed for filling and emptying. These tanks are tested at 56 kg/cm^2.

When it is necessary to use higher pressures to arrive at a more economical method of transport e.g. for oxygen and helium, hollow-forged or drawn seamless tanks are used. These tanks have an outer diameter of 380-510 mm. and 25 to 30 of them are placed together on a flat car which scarcely differs from the standard model.

It is clear that the technique of transporting gases and liquids under pressure does not differ greatly in the United States and Europe.

Safety regulations

The products carried in tank cars are often inflammable and dangerous and are frequently transported under pressure. It is therefore natural that safety regulations should be imposed by the authorities. The Interstate Commerce Commission has issued regulations which are incorporated with those of the Association of American Railroads, Mechanical Division, and concern details of car design, construction and operation. These specifications now cover 29 different types of tank cars.

Transport of solid products

Solid products in powder form are in some cases shipped in bulk in box cars. This is the most common method for grain, chemical products being usually carried in self-clearing hopper cars which can be unloaded through bottom doors. Products which must be protected against rain and water are shipped in weather-tight, covered hopper cars which are loaded through hatches in the roof. They are usually emptied in the same ways as open hopper cars, but sometimes the bottom doors are designed to permit the bottom of the covered hopper to be connected directly to the conveying equipment of the recipient. The contents of the car can then be unloaded into his storehouse without contamination or loss.

The Association of American Railroads has adopted two standard types of open hopper cars with capacities of 45 or 64 tons, but there are many other types with capacities of 50, 54, 68, 73 and 82 tons. Furthermore there are special hopper cars for the transport of iron ore.

Covered hopper cars are often privately owned and the types vary widely with the products to be shipped. For example, a covered hopper car intended for the bulk transport of cement has a capacity of 64 tons. Its cubic capacity is 50.97 m^3 and its light weight 22,816 kg.

Flour and many other powdery products of low cubic weight often have a tendency to bridge and pack, and for this reason it has until recently been impossible to transport such materials in bulk. The

General American Transportation Corporation has designed a covered hopper car (Trans-Flo) for this purpose, which can be unloaded without introducing any internal device for loosening the contents or breaking any bridges that may have been formed. The car is divided into two airtight compartments and is unloaded pneumatically from the bottom of each hopper. During unloading, a vibrator mounted in the unloading connection at the bottom of the hopper operates continuously to speed up the flow and to keep the product moving uniformly through the hoppers.

The capacity of the Trans-Flo cars is 50-60 metric tons.

Car leasing

Many types of cars, such as tank cars, refrigerated cars, and certain types of hopper cars and box cars, are considered as special equipment, and according to current rules, the railway companies are not obliged to supply such special equipment to the shippers. If a commodity is to be shipped in a type of car not normally supplied by the railway company, the shipper has either to maintain his own fleet of cars of that type or to hire the cars from a company which specialises in car-leasing. Among these car-leasing companies are the following : General American Transportation Corporation, North American Car Corporation, Union Tank Car Company, Shipper's Car Line Corporation.

The present rent of tank cars amounts to $40-150 per month, depending on capacity and type. The car-leasing company places the car at the shipper's disposal and carries out the necessary repairs to maintain the car in good condition. The car-leasing companies mentioned above have their own repair shops all over the country. The railway company charges the shipper the normal freight rate and pays a " mileage " to the car owner. For tank cars this " mileage " at present amounts to 2 cents per mile, and if it is paid to a car-leasing company, it is credited to the shipper's account up to the full amount of the rental.

For many shippers and especially for those whose need of cars varies over the year due to seasonal or other fluctuations in business, it seems to be more economical to rent cars than to maintain their own fleets. The car-leasing companies can undoubtedly give shippers with varying requirements a more flexible transport service at lower cost than the shippers are able to arrange themselves. In addition the car-leasing company is often in a position to find return loads and thus eliminate non-revenue runs by the cars.

Large car-leasing companies of this type are not common in Europe where it is usual for the individual firms to have their own tank cars and other special cars. It is however possible in some countries to hire tank cars and refrigerated cars.

Statistical information

The number of railway freight cars of different types in the United States is shown in Table 11 which is compiled from the statistics issued annually by the Interstate Commerce Commission.

Table 11. Number of railway freight cars in the United States for the year ending December 31st, 1948

	Owned by railway companies	Privately owned	Total
Box	738,588	no information	738,588
Flat	67,232	no information	67,232
Stock	49,918	3,899	53,817
Gondola and hopper (open and covered)	889,908	7,174	897,082
Tank	8,806	136,895	145,701
Refrigerator	20,233	111,263	131,496
Caboose	24,660	—	24,660
Other freight cars	10,382	2,333	12,715
Total	1,809,727	261,564	2,071,291

Transport of iron ore and coal by belt conveyor

At the Stone and Webster Engineering Corporation an interesting and important case of potential competition between transport by rail and by belt conveyor was discussed. At present very large quantities of coal and iron ore are transported by rail in opposite directions over a distance of about 150 km. between the Ohio shore of Lake Erie and an island in the Ohio river. The possibility of replacing this rail transport by belt conveyors, one for iron ore and one for coal, is now under consideration.

The salient features of the " Riverlake Project ", as it is called, are summarised in Table 12.

Table 12. Salient features of the " Riverlake Project "

	For iron ore	For coal
Length of belt system	147.5 km.	147.5 km.
Belt capacities	4,250 tons/h	3,080 tons/h
Belt width	54 in.	66 in.
Belt speed	11 km/h	11 km/h
Number of conveyor units	211	127
Min. length of conveyor unit	120 m.	229 m.
Average of conveyor unit	700 m.	1,220 m.
Max. of conveyor unit	2,085 m.	2,890 m.
Total length of belts	301,000 m.	299,000 m.
Total h.p. for conveyor motors (name plate ratings)	111,875 h.p.	71,775 h.p.

Total quantity of steel required	about 270,000 tons
Estimated cost of belts only	about $56 millions
Estimated total cost of project	about $300 millions

One of the chief technical difficulties with belt conveyors of this magnitude is to secure sufficient friction between belt and driving-drums to transmit the necessary power. The arrangement with two motor-driven drums shown in figure 12 has been adopted in the design.

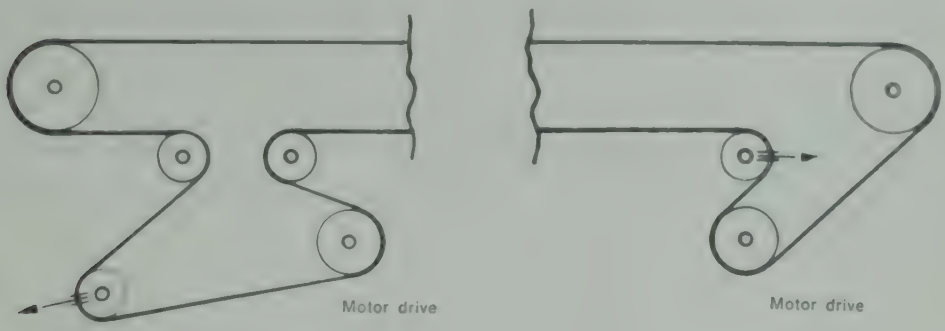

Fig. 12. Arrangement of driving Pullies for long Conveyor Belts.

Maintenance of this system is likely to be expensive and it is not clear whether it will prove an economical proposition. No decision to construct the conveyor system has yet been taken.

The economic advantages of the belt conveyor system are obviously very much greater for shorter distances, and it is likely that this method of transport will be used in such cases even if the tonnage of material to be transported is much smaller than in the above project.

Transport of natural gas by pipeline

The most impressive achievement in the field of transport by pipeline in the United States is undoubtedly the distribution of natural gas throughout the whole country, except New England and the North West Pacific States. Although the Mission did not visit such installations, it heard a very interesting lecture on the subject by Mr. A. S. Wolfner of Stone and Webster Engineering Corporation. The main points of this talk are given below.

Production and consumption of natural gas in the United States

There are three main sources of natural gas :

1. Natural gasfields (45 %).
2. Crude oil containing dissolved gas (35 %).
3. So-called distillate fields (20 %).

Natural gas is thus found either alone or dissolved in crude oil or natural gasoline. The gas from the natural gasfields is often contaminated with hydrogen sulphide (up to 6 %) or carbon dioxide and must be specially processed.

The most important fields are situated in Texas, Louisiana, New Mexico, Kansas and Oklahoma. At present about one-third of the gas leaves the producing states and is transported to other states by pipeline.

No less than about 15 % of all energy used in the United States is derived from natural gas. The known deposits of natural gas in the United States are greater than the known oil deposits and correspond in heating value to about 6 3/4 billion (6.75×10^9) metric tons of coal. At the present rate of utilisation the known deposits will last for only 26 years.

Natural gas is a high quality fuel (9,000 cal. per standard m^3) ideal for domestic use and for space heating, as well as for special industrial purposes. Its natural markets are the large urban centres which lie at a considerable distance from the sources.

The pipe line

The gigantic transport problem of distributing this gas all over the country was solved with the development of large-diameter steel pipes and modern welding methods. New construction and earth-moving machinery and special methods of corrosion protection were also of great help. There are now about 175,000 km. of pipelines in operation, of which 30 % are of 56 cm. diameter or larger. Several transmission systems handle more than 30 million m^3 of gas per day.

In spite of the long distances between the producing and consuming areas the gas can be delivered to the large urban centres of Los Angeles, Chicago, Cleveland and New York at wholesale prices ranging from $ 0.80 to 1.40 per million k/cal. according to the distance. This compares favourably with other fuels and is much cheaper than manufactured gas. The actual transport cost is about $ 0.04 per million k/cal. per 100 km.

The design of modern, high-capacity pipelines is based on the use of electric-welded steel pipe of up to 31 in. diameter and down to 1/4 in. thickness. Existing regulations and the American standards for pressure piping permit working stresses in gas transmission lines equal at most to 72 per cent of the minimum yield point. Higher safety requirements are imposed for pipelines within the boundaries of cities or villages. Pipes are now available with a minimum strength of 52,000 lb. per sq.in. or 3,650 kg. per cm^2. Working stresses of up to 37,500 lb. per sq.in. (2,630 kg. per cm^2) can therefore be permitted ($<$ 0.3 % C and 1-2 % Mn). Usually lines are designed for a maximum service pressure of 800 lb. per sq. in. (56 atmospheres), but this pressure is sometimes exceeded. Under normal conditions of line design and compressor station spacing a 26 in. diameter line will be good for handling about 9 million m^3 of gas a day. A 30 to 31 in. diameter line will handle about 13 million m^3 per day. The finished pipe is carefully inspected, but not tested for leaks, before being buried in the ground. The testing is done afterwards with gas pressure, and very exceptionally a leak is found with a torch.

At pipe line pressures natural gas is about 7-10 % more compressible than would appear from the ideal gas laws. Hydrate formation can

occur at gas temperatures as high as 15°C (60°F) at a pressure of 56 atmospheres (800 p.s.i.) and may cause blockage of the lines.

Processing of the gas

Before natural gas can be put into the transmission line, it has to be gathered in the fields, metered and brought to full line input pressure. The gas must be processed to render it fit for pipeline transport. The field installations include a variety of processing plants. Hydrogen sulphide is removed from the natural gas by a regenerative amine absorption process, and reduced to about 10 p. p. m. The heavier gas components comprising propane, butane and gasoline fractions are removed by oil absorption and sold as by-products. If these fractions were not removed, they would separate in the line and interfere with the gas transmission. Water vapour is removed from the gas either by contact with glycol or through absorption over aluminium oxide.

Compressor stations

In order to compensate for the pressure drop, compressor stations are installed at regular intervals, normally 90-160 km. In general, gas transmission costs will be at a minimum when the compression ratio is kept small and booster stations are relatively close.

Modern gas transmission lines of high capacity operating at 56 kg/cm² working pressure will usually have compressors designed for a booster ratio in the range of 1.3 to 1.6. At these values the installed compressor horse-power requirements will vary from 700 to 1,050 h.p. per million m³ of daily flow volumes. Most of the compressor stations use reciprocating, single-stage compressors, driven by directly connected gas engines. The specific fuel consumption has now been reduced to less than 2,000 k/cal. per horsepower, but the fuel requirements on long pipelines amount to a considerable portion of the gas volume handled, sometimes as much as 10 to 15 per cent.

In recent years, a lively controversy has arisen in regard to compressor equipment. Centrifugal compressors, driven either by electrically-operated motors, condensing steam turbines, or gas turbines, have appeared as strong competitors to the usual gas engine and reciprocating compressor. Their fuel consumption is higher, but their greater capacity reduces the number of units required and simplifies station design. The builders of reciprocating compressors have responded to the challenge by developing new engine designs of up to 2,600 h.p. and by further reducing the fuel consumption. These improvements seem to ensure the continuous application of the reciprocating compressor in this field.

A typical booster station forms a self-contained installation, deriving its fuel from the gas line and meeting its own requirements of cooling water and electricity, as well as housing for the employees. The principal building contains the compressor engines, with intake filters for the combustion air and exhaust mufflers located outside. The

compressors are usually arranged in a straight line or a single row of parallel engines. Sometimes, when the installed horsepower is very large, the engines are installed in double rows to shorten the building and facilitate plant operations. Some gas compressor stations house more than 30,000 h.p. capacity under a single roof. The installed engine capacity in the gas pipeline operating under the Federal Power Commission regulations is now in excess of 3,000,000 h.p.

The dissipation of engine heat plays an important role in booster stations, since about 45 per cent of the heat of combustion must be removed from the gas engine jackets, the engine lubricating oil coolers, the compressor cylinders and the compressed gas itself before it reenters the pipeline. Compressor stations are usually erected in localities where no outside source of water is available. The station must therefore contain a source of fresh water, a water reservoir, treaters and filters and a system of circulating pumps and atmospheric cooling towers. Usually, there are two distinct cooling circuits : one for high temperature water for use in gas engine jackets cooling at about 75°C and a second at about 40°C for all other purposes. The auxiliary equipment is normally electrically driven, and electric generator sets form part of the compressor station equipment.

The gas coming from the line may contain rust and other impurities and must pass through gas scrubbers before entering the station intake manifold. The gas is cooled before it is returned to the transmission line.

Booster stations are normally designed for a minimum of operating personnel; automatic engine regulation and many other automatic controls are therefore used.

Storage facilities

High pressure storage tanks allow the line to be run always at almost maximum capacity. They should be spherical and placed outside cities.

Horton spheres and spheroids

In the chemical and petroleum industries storage of liquids and gases is an important factor. Raw materials, intermediates and finished products must be accumulated to prevent disturbances in regular deliveries or because shipment takes place in large lots at regular intervals.

In the United States, as well as in European countries, storage vessels in the shape of horizontal or vertical cylinders with or without roof are extensively used. Vertical tanks with floating roofs are used to reduce evaporation losses from volatile liquids with moderate vapour pressures. These types are well known and this report will be confined to some less common designs of storage vessels which are seldom or never used in Europe, namely the spherical and spheroidal types. The

basic ideas for these vessels were developed by Mr. George T. Horton, son of the founder of the Chicago Bridge and Iron Company and in recognition of his work these vessels are called respectively Hortonspheres and Hortonspheroids.

The Hortonsphere

One way to avoid evaporation losses of volatile liquid is to design the storage vessel to withstand the maximum internal pressure resulting from the vapour tension of the liquid. The quantity of material required for the construction of these vessels increases rapidly with the pressure, so that shape becomes very important. For the most economical design the material from which the vessel is constructed should be stressed equally in all directions in order to reduce the weight per unit of capacity to a minimum. The true sphere fulfils this requirement.

The Hortonsphere is built to this ideal shape and is used for storing volatile fractions of natural gasoline, butanes, butane-propane mixtures and anhydrous ammonia.

Many liquids, such as anhydrous ammonia, have too high vapour pressures at ordinary temperatures, and are most economically stored at reduced temperatures in well-insulated spheres. The necessary refrigeration is best produced by allowing some of the liquid to evaporate, by compressing and condensing the vapour and returning the condensate to the storage vessel. In this way, liquid ammonia can be stored under a pressure of only 5.3 kg/cm^2 gauge at about 6°C. Lower temperatures cause insulation difficulties. This type of storage installation for liquid ammonia is also used in Europe.

Hortonspheres are built in capacities ranging from 160 m^3 to 4,000 m^3 and for pressures up to 10 kg/cm^2 gauge.

The size and pressure of the Hortonsphere are limited by the requirement of a safety factor of 4 or 5. Where plain steel is used for this purpose its thickness does not exceed 32 mm., and if the combined factors of pressure and volume lead to a plate thickness greater than 32 mm., multispheres consisting of a number of spheres built one on top of the other are used. In one case a multisphere was built with a capacity of 150 m^3 and a pressure of 17.5 kg/cm^2 gauge.

The Hortonspheroid

When storing a liquid with a moderate vapour pressure it is evident that the stresses in the shell are more dependent on the hydrostatic pressure of the liquid load of the tank than on the gas pressure above the liquid level. Consequently, the ideal shape for such a vessel is that of a drop of liquid resting on a flat surface which is not being wetted by the liquid.

The plain Hortonspheroid has been designed to this ideal shape. It consists of a self-supporting steel shell provided with an outside ring girder and a series of brackets to support the overhang load. No inside framing is employed.

When the size of the vessel increases, the forces resulting from the

weight of the shell contribute substantially to the stress, and beyond a certain size, which also depends on the maximum internal pressure, it is necessary to employ internal trussing. The purpose of this trussing is to support the roof when the vessel is not subjected to internal pressure and to serve as ties when the vessel is under pressure. For reasons of design the shell has one or more nodes. This type of Hortonspheroid is called the noded Hortonspheroid.

In the smaller sizes, vessels for low pressures are built with cylindrical shells with curved bottoms and roofs. These are called respectively Hemispheroids and noded Hemispheroids. This design requires more steel than the Hortonspheroids, but the cost of manufacturing and erecting the cylindrical shell is less, thus resulting in a lower total cost.

The spheroids are built for capacities from 320 to 16,000 m^3 and are primarily used at oil refineries and storage terminals for motor and aviation gasoline. A working pressure of 0.18 kg/cm^2 gauge was stated to be sufficient to prevent all standing storage loss.

Construction

The Hortonspheroids and Hortonspheres are built of steel plate and erected on the spot. The steel plate can in certain circumstances be clad or lined in order to prevent corrosion and contamination. The plates are joined by butt welding. The Hortonspheroids, which also have curved bottoms, are designed to rest directly on the ground, which must be prepared with a sand cushion 6 inches thick. The Hortonspheres are erected above the ground and supported by a number of tubular columns attached to the shell at the equator.

The tanks are also provided with standard accessories including safety discs, liquid gauges and sampling devices.

Choice of type of storage vessel

Table 13, which has been compiled from information submitted by the Chicago Bridge and Iron Company, shows the type of vessel which is the most economical for a given size and pressure.

Table 13. MOST ECONOMICAL TYPE OF STORAGE VESSEL

CAPACITY M^3	*Working pressure, kg/cm² gauge.* UNDER 0.18	0.18-0.35	0.35-0.70	0.70-1.40	1.40-2.20	2.20-10
300-1,600	PH	PH	PS	PS	PS	S
1,600-3,200	PH	PS	PS	PS	PS	S
3,200-4,800	NH	NS	NS	PS	PS	S
4,800-19,000	NS	NS	NS	NS	PS[1]	—

1. For pressures in this range vessels do not exceed 6,400 m^3 capacity.

Key to the letters in the table :

PH = Plain Hemispheroid.
NH = Noded Hemispheroid.
PS = Plain Hortonspheroid.
NS = Noded Hortonspheroid.
S = Hortonsphere.

The choice of type for a given application will also depend on such factors as temperature, corrosive conditions, ground conditions, etc., but is not likely to be very different in Europe from what it would be in America.

Conclusions

1. Car-leasing companies in America contribute effectively to the lowering of transport costs by helping their customers to overcome peak loads, by giving them the benefit of cheap repair and maintenance in central shops, and by utilising return loads.

2. Although bulk transport is also extensively used in Europe for such products as liquids and gases under pressure and for solids with relatively low melting points, it is not applied to as many different products as in the United States.

3. The rail cars used for bulk transport in the United States are generally larger than in Europe, thus giving a more favourable ratio of load to light weight.

4. Tank cars are standardised in America, and 29 different types are in use.

5. The " Riverlake Project " illustrates the enormous potentialities of the belt conveyor for transport of solid materials over considerable distances.

6. The problem of distributing natural gas over practically the whole of the United States has resulted in important developments in pipeline construction likely to be of great value in other fields.

7. The introduction of the Hortonsphere and spheroid has made it economically feasible to store large volumes of liquid under pressure.

Recommendations

These conclusions lead to the following recommendations :

1. The type of service given by the car-leasing companies in America should also be provided in Europe.

2. Europe should consider increasing the number of products shipped in bulk, increasing the size of car loads, and standardising the types of cars.

3. A wider application of belt conveyors and pipelines for bulk transport over considerable distances should be considered in Europe and the wide American experience in these fields should be utilised.

4. The attention of European industrialists is also drawn to the advantages of the Horton storage vessels for liquids with high vapour pressures.

XII

FINAL CONCLUSIONS

Everyone is aware that the chemical industry in the United States has expanded enormously during recent years. Nevertheless, to bring this point home, it may be recalled that in 1949 two-thirds of the world production of synthetic organic products were produced by the American chemical industry, or 8 million tons out of 12 million. If it is remembered that in 1917, the date when the U.S.A. entered the war, the American chemical industry was comparatively undeveloped, while in Europe, and especially Germany, large quantities of chemical products were already being produced, it will be realised how rapidly industrial leadership has shifted from Europe to America.

It is therefore vitally important for the European chemical industry to detect the fundamental causes of this development and study how to regain a more prominent position, if possible.

Many reasons may be put forward which partly explain the extraordinary development of the American chemical industry, in particular, ample supply and easy working of raw materials, two world wars, the existence of wide markets, the spirit of enterprise in industry and a taste for novelty on the part of the consumer, but such an analysis was not within the scope of this Report.

On the other hand, in view of the unanimous statements of the American experts met by the Mission, it must be emphasized that a large part of the success of the great American achievements in industrial chemistry is due to the efficiency of the chemical engineer. The action of the chemical engineer is decisive when a process has to be transposed from the laboratory to the industrial state. For this reason, several chapters of the Report have been devoted to the training of the chemical engineer.

The reader will have realised the fundamental difference between the modern concept of education, quantitative and essentially practical, as given in the American universities and technical institutes of chemical engineering, and the European tradition of descriptive theoretical courses, often lagging behind industrial development and frequently attaching exaggerated importance to the historical side.

In the United States, the best chemical engineers are recruited for posts of " job engineers ", who are responsible for the complete installation of workshops and plants based on designs prepared by the design engineers, with their collaboration.

The task of the job engineer is highly complex and very difficult; he has to keep in touch with all services of the firm and the customer, co-ordinate the efforts of each in order to finish the work within the prescribed time-limit and without additional expenditure. He must pay very close attention to the efficiency and the output of his team. The extreme importance attached to team work is incidentally one of the characteristics of the American method.

Another point to be emphasized is the tendency to specialisation, which is carried in the United States to a degree unknown in Europe. Specialisation exists not only within the firms, but also in the distribution of work among various firms. The Mission had occasion to visit some firms of constructors specialising extensively in particular equipment required by the chemical industry. Lastly, the importance of not doing anything which others can do better is particularly appreciated in the United States.

But extreme specialisation of staff or of firms would not alone be sufficient to lead to better results; leaders of European industry would therefore commit a serious error in seeking solely to increase specialisation and follow the American pattern of distribution of labour without first seeing that the whole staff are convinced of the absolute necessity for complete, sincere co-operation between and within the various services. The authors of this Report feel that in this connection valuable lessons may be learned from the staff training and promotion methods used in the United States, which are based on the following overriding principle : " the good management of a firm implies not only that the most capable and most conscientious are placed at the controls, but that the less talented also give of their best, co-operating wholeheartedly and ungrudgingly ".

ANNEXES

ANNEX I

ITINERARY OF THE MISSION

27th September 1950	Arrival in New York (N.Y.).
29th September 1950	Visit to the M.W. Kellogg Co., New York (N.Y.).
2nd October 1950	Visit to the Lummus Company, New York (N.Y.).
3rd October 1950	Visit to the Foster Wheeler Corp., New York (N.Y.).
4th October 1950	Visit to the Houdry Process Corp., Marcus Hook, Pa.
5th October 1950	Visit to the Sun Oil Company, Philadelphia, Pa.
6th October 1950	Visit to the Brown Instrument Division, Minneapolis Honeywell Regulator Company, Philadelphia, Pa.
6th October 1950	Visit to the Leeds and Northrup Company, Philadelphia, Pa.
9th October 1950	Reception by E.C.A., Washington, D.C.
9th October 1950	Visit to the National Bureau of Standards, Washington, D.C.
10th October 1950	Visit to the Koppers Company Inc., Pittsburgh, Pa.
11th October 1950	Visit to the Chemical Plants Division, Blaw-Knox Construction Co., Pittsburgh, Pa.
12th October 1950	Visit to the Alleghany Ludlum Steel Corp., Pittsburgh, Pa.
12th October 1950	Visit to the Aluminium Company of America, Pittsburgh, Pa.
13th October 1950	Visit to the Babcock and Wilcox Co., Barberton, Ohio.
16th October 1950	Visit to Podbielniak Inc., Chicago, Illinois.
17th October 1950	Visit to the A.O. Smith Corp., Milwaukee, Wis.
18th October 1950	Visit to the General American Transportation Corp., Chicago, Illinois.

19th October 1950	Visit to the Chicago Bridge and Iron Company, Chicago, Illinois.
20th October 1950	Visit to the Pfaudler Company, Rochester (N.Y.).
23rd October 1950	Visit to the Stone and Webster Engineering Corp., Boston, Mass.
24th October 1950	Visit to the E.B. Badger and Sons Co., Boston, Mass.
25th October 1950	Visit to the Bird Machine Company, South Walpole, Mass.

In addition, some of the Members of the Mission individually visited a few other firms and institutions.

ANNEX II

QUALIFICATIONS FOR AN ACCREDITED UNDERGRADUATE CURRICULUM OF CHEMICAL ENGINEERING

Prepared by the Chemical Engineering Education and Accrediting Committee of the American Institute of Chemical Engineers.

February, 1951

The following list of qualifications is drawn up for the guidance of members of this Committee, of inspectors operating for the Committee and of deans and heads of departments of schools not yet accredited. They must not be regarded as " hard and fast " rules but should be interpreted with good judgment in the light of local conditions. They are intended to aid the Committee in giving uniform treatment to all cases that come to its attention and to assist the administrative officers of non-accredited schools in determining the steps to be taken to bring a department of chemical engineering to the point where it is ready for an inspection.

Viewed from another angle, these qualifications are an attempt to put down in concrete form a summary of the principles underlying best current practice in chemical engineering education. It is far from our intention to freeze this practice into a rigid pattern that would be blindly followed to the detriment of all progress. The Committee is anxious to encourage any new ideas that hold promise of a real advance in the field and to that end it will be receptive to departures from what it considers to be usual good practice at the present time, as set forth in these pages.

It is to be noted that " curriculum " is here used in a very broad sense and is intended to include not only the sequential assemblage of courses leading to a degree in chemical engineering but also the personnel and facilities of the departments or divisions of a school which offer the various courses therein.

The qualifications are as follows :

1. Administration. The Committee favours a separate department of chemical engineering enjoying a status equal to that of other departments of engineering in all respects, including control of curriculum, personnel, and budgets. This implies a departmental budget comparable to that of other engineering departments. It implies control of the curriculum subject only to review by higher administrative authorities or committees representing the school as a whole. It is recognized that a strong division of chemical

engineering may flourish in some cases though not organized into a separate department on a par with other branches of engineering. This is to be regarded as an exception rather than the rule, justified in certain cases by unusual local conditions but to be remedied as soon as practicable.

2. Faculty. The number of staff members and their ranks will naturally depend on the number of students both undergraduate and graduate, but the Committee believes that *three full-time members* is the minimum for any school. The Committee does not believe in specifying any definite ratios of students to faculty because such figures have little meaning and are too easily misinterpreted. The ultimate criterion for the proper number of faculty members is the teaching load and that is discussed a little later under that heading.

At least one of the staff members should hold the rank of full professor and one (not necessarily the same one but preferably so) should be qualified for active membership in the American Institute of Chemical Engineers. Graduate assistants should not be used as chief instructors in charge of any course, but only as assistants under the direction of a more experienced teacher.

It is highly desirable that some of the faculty members be graduates of other institutions than the one to which they are attached. It is desirable that faculty members have a background of industrial experience.

3. Research and professional work. One of the best indications of a live and growing (in a professional sense) faculty is the amount and quality of research or professional activities in which its members are engaged. Even if a school offers no graduate work, every teacher of chemical engineering should be making an original contribution to the advancement of our knowledge by engaging in research on his own or developing his own capacities as an engineer by high grade professional work. The broadening of his knowledge and experience in this way will be reflected in better teaching and will be of the greatest aid in arousing the interest and respect of the students.

The school administrative officers should foster the growth of engineering teachers in professional stature by encouraging attendance at meetings of professional societies, the undertaking of professional work of a dignified character, and in other ways.

4. Curriculum. Considerable latitude in the choice and arrangement of subjects in the curriculum (here used in its narrower sense) is favoured by the Committee, but certain general principles are recognized as essential and should be adhered to. These may be briefly stated and explained as follows :

a) Emphasis on the fundamentals and avoidance of narrow specialization.

Courses in all subjects of science and engineering should tend toward breadth of scope rather than narrow specialization, and should be primarily concerned with fundamental principles and their applications to a wide variety of cases. Specialized courses in analytical chemistry or in the technology of particular industries, or so-called " practical " courses will be viewed with disfavour. This is not because such courses are valueless, but because they crowd out of the curriculum the more valuable fundamental courses.

b) Thorough grounding in the basic sciences as early as possible in the curriculum.

This should occur as far as possible in the first two years (or three years in the case of a five-year course). It is recognized, however, that the chemical engineering student needs a particularly good foundation of chemistry, and courses in this science must be extended into the next year. No basic science courses should be left to the last year of a four-year curriculum. Basic sciences that must be included are: chemistry (including major divisions, namely, inorganic, analytical, physical, and organic), mathematics through integral calculus, and physics.

c) Humanistic or non-technical studies.

There has been an active discussion as to the quantity of "non-technical" or "humanistic and social studies" that should be included in an engineering curriculum. Some urge a humanistic stem or regular sequence of such courses in each term of the four years.

Others favour a varying range of free choice for the student to pursue his individual interests. Still others favour a pre-engineering course in humanities followed by complete concentration on science and engineering. The Committee prefers either of the first two procedures rather than the third, but is not so much concerned with the exact procedure as it is with insuring that the student receives as broad an education as possible consistent with a sound scientific and engineering education and that the student has the opportunity and is encouraged to pursue his human interests.

d) Emphasis on the quantitative aspects of science and engineering.

The Committee strongly recommends that all courses in science and engineering be made as quantitative as possible and purely descriptive matter be kept to a minimum. Fundamental principles are best illustrated by numerical problems but care should be taken in framing a problem statement to see that the principle is truly revealed and not obscured by a mass of calculations that are purely manipulations and require little thought or application of principles. The slavish use of formulae picked out of handbooks and textbooks without real understanding is, of course, to be deprecated and the teacher must see to it that his numerical problems do not degenerate to ones of this type.

e) Laboratory work in both science and engineering courses is essential to illustrate and apply principles.

The objective stated in the heading is probably the principal one for all laboratory work but there are other important reasons for it. Among these may be mentioned the confidence gained by the student in handling engineering-type equipment, the rendering of the subject matter of a course more real and the acquiring of certain skills which will be useful to him in the early stages of his career after leaving school.

f) Courses in the unit operations and chemical processes of industry approached through the application of important principles are the backbone of a chemical engineering curriculum.

It is not enough that the engineering student learn the fundamental principles of the pertinent sciences, he needs to be taught to apply them to engineering problems. The best means so far devised to do this for the student of chemical engineering is to begin by breaking down industrial processes into unit steps which are then studied from a fundamental viewpoint without relation to any one industry or integrated process. These may be said to constitute the fundamentals of chemical engineering. The

exact nature or sequence of the work in unit operations and processes is not of paramount importance. Considerable variation may and does exist between accredited curricula.

To give a somewhat more specific picture of what such courses should include without at the same time being too dogmatic is not an easy task but the following statement may be helpful as a general guide :

Thorough training should be given in the *fundamentals* of the more basic unit operations, such as, flow of fluids, heat transfer, general theory of the mass transfer operations, and in material, energy, and economic balances; fuels and combustion; applied chemical and chemical engineering kinetics; materials of construction as they affect plant investment, maintenance, safety, and product quality and cost; together with the measurement and control of operating variables. Carefully selected industrial processes should be used to illustrate the need for, and the value of, the above-mentioned studies.

g) Thorough instruction in general engineering fundamentals is essential, and should be completed before the last year.

The curriculum should include strong courses in engineering drawing, electrical engineering, engineering mechanics, strength of materials, and the properties of materials or physical metallurgy. These courses should be designed to meet the needs of the chemical engineer rather than the specialist in the field covered, and should constitute an integral part of the whole programme with the material covered in these courses required for, and used in, the integrating courses of the last year.

h) The thermodynamic approach to problems of science and engineering is a valuable tool.

The curriculum should include a course in thermodynamics from the point of view of application to chemical engineering problems. The Committee favours the view that this course be given by a chemical engineer from this point of view.

i) Instruction in reporting is an essential part of the engineer's training.

The Committee believes that instruction in reporting, both oral and written, should be given under the auspices of the chemical engineering department and well integrated with other chemical engineering subjects since only in this way does the student have a live and interesting subject on which to report. Such a motivation is absolutely essential to the success of any instruction in reporting. The project work of the senior year offers an excellent opportunity to give the students practice in this important field.

Stereotyped reports, such as are sometimes used to present the results of laboratory experiments, are not considered a satisfactory substitute for a report on some project — either laboratory, literature survey, design, or other type — upon which the student has been engaged.

Instruction in reporting involves not only practice by the student but detailed constructive criticism of the student's efforts by the instructor so that he learns to profit from his early mistakes.

j) The major emphasis in the last year should be placed on the integration of previously learned facts and principles by means of project work.

By the term " project work " is meant the application of various disciplines to the solution of comprehensive problems which cover a broader field than the usual short problem given in a course or the work of the student on a design problem or a laboratory investigation or a cost analysis.

The project is characterized by the fact that it cannot be solved by a few fundamental considerations or by formulae and a limited set of data, but requires the exercise of considerable thought and judgment in planning the attack and the bringing together of many facts, principles and techniques in executing the work to arrive at the goal. The exact subject matter of the project and the name of the course in which the student meets this type of experience is relatively unimportant. Typical course names under which such work is given are plant or process design, comprehensive problems, economic balance, laboratory project, research, thesis, chemical processes, and the like. The objectives of such work should be the integration of earlier work, and the development of the student's ability to screen the problem for its major variables and their order of magnitude thereby developing a basis for sound engineering judgment.

5. Teaching loads. Every engineering teacher should have a reasonable proportion of his time available for research or other forms of professional work. With this in mind, the Committee is insistent that the teacher should not be so overburdened with teaching or committee or routine administrative work or combinations of these activities that he cannot develop himself professionally.

The Committee believes that it is not feasible or desirable to state any specific number of course or credit hours or clock hours that should represent the maximum teaching load because figures of this kind are not comparable as between different schools and different types of courses. We believe that the total hours spent by the teacher in his teaching duties, whether in laboratory or classroom, in correcting and grading problems, in preparation for classes, reading reports or supervising projects and research by students or in administrative work, should not exceed 30 hours per week.

6. Methods of instruction. The methods followed by any particular instructor in putting across to the student the subject matter of his course is a strictly individual matter and the Committee has no intention of laying down any rules restricting the freedom of an instructor to use any methods he considers effective. There is, however, one general principle that is most important in all engineering instruction and should be emphasized, namely, that small sections in all class and computation work and small groups in laboratory work are essential for satisfactory instruction. The number of students in any section should not exceed approximately twenty-four and should preferably be somewhat less. In some courses it is recognized that it may be desirable to give part of the course as lectures to a larger group and then break down this group into small sections for recitation, discussion, computations, or laboratory work.

In performing a laboratory experiment, the number of students assigned to a given experiment should not be more than is necessary to execute the experiment efficiently. In some cases this means that only one student should perform the experiment; rarely will it be desirable to assign more than three men to a single experiment.

A fundamental requirement is that the teaching staff must be jealous of its standards and insist upon high standards of performance on the part of the students in all respects including speaking, writing, reading, and in human relations as evident in their daily lives. These standards are best established by the example set by the staff.

7. Chemistry courses. In most schools the elementary courses in inorganic, organic, analytical, and physical chemistry will be the same as those given to students majoring in chemistry, and if the chemistry course has been accredited by the American Chemical Society, this fact will be given weight but it does not relieve the inspector of the responsibility of making his own examination to determine their suitability as parts of the chemical engineering curriculum. If the courses offered to chemical engineering students differ materially from those of the accredited chemistry curriculum, or if the latter is not accredited, a more thorough examination should be made. It is not unreasonable that chemistry courses for chemical engineering students should cover somewhat less ground, especially in analytical chemistry, than the corresponding courses leading to a degree in chemistry. On the other hand, they should be fundamental, quantitative, and rigorous and should include adequate laboratory work. The methods of instruction and quality of this instruction should be no different. The difference should be only in emphasis.

8. Laboratory facilities in chemical engineering. An acceptable course in chemical engineering presupposes a laboratory where unit operations and processes can be carried out on equipment which is of sufficient size to yield performance data that would be reasonably representative of the same type of equipment used in chemical industry. Every laboratory should have equipment for carrying out the operations of crushing and grinding, filtration, heat transfer, fluid flow, evaporation, drying, distillation and gas absorption as a bare minimum. A well-equipped laboratory will have more than one type of equipment for each of these operations and will have, in addition, equipment for various other operations and for some of the organic chemical processes such as nitration, sulphonation, reduction, hydrolysis, and the like.

The laboratory facilities should also include a machine shop with adequate tools for construction and repair of engineering equipment and a full-time mechanic. They should also include a considerable number of measuring instruments such as flow-meters, thermometers, pyrometers, ammeters, voltmeters, wattmeters, potentiometers, pressure gauges, hydrometers, scales and balances, and the like.

9. Library. The actual number of books and journals that would strictly be required for use by the students in an undergraduate course is very small, but the library facilities should go well beyond this minimum and provide reference books and journals for collateral reading by the students and to assist the faculty in research and professional work. The Chemical Engineering Education Projects Committee has prepared a list of books recommended for the library of a school teaching chemical engineering and this will serve as a useful guide. This list is not a static one but is continually being revised and added to.

A more important point than the exact number or titles of books and other references is that they be readily available in a convenient location on an open-shelf basis to all students so that they will form the habit of using the library. Whether the books and journals are in a main library or in a separate departmental library is immaterial as long as the principle of accessibility is adhered to.

10. Graduates from the curriculum. In general a school applying for accrediting should be able to produce records of graduates from the curriculum for which accreditation is requested for a period of at least

three years. The fact that such graduates are making a creditable record in the profession or in graduate work at other institutions is a factor to be considered in accrediting.

The requirements of three years is not to be regarded as a rigid one to fit all cases but may be modified by circumstances. It applies more particularly to schools that have just introduced chemical engineering courses or have made major changes in their curriculum and facilities. It does not for instance mean that schools which were previously close to having an accredited curriculum and have made certain improvements to meet the views of the Committee will have to wait until three classes have graduated before applying for accrediting.

11. Appraisal of the department and curriculum as an integrated whole. The qualifications set forth in these pages are not to be regarded as fixed standards. They are intended as guides to what the Committee recommends as good practice. There is no required curriculum, no required laboratory facilities, no required form of department organization, or other fixed requirements. Each curriculum must be regarded as an individual case and judged as a whole with due regard for all the circumstances, some favorable and some unfavorable. In other words, this is not a set of rules to be followed blindly. In the last analysis the appraisal of a given curriculum is based on the best judgment of the members of the Committee acting as consulting experts.

ANNEX III

THE ENGINEERING ORGANISATION OF A BIG CHEMICAL ENGINEERING FIRM

This annex is an extract from a lecture given by the vice-president of a large company of chemical equipment manufacturers.

The Company employs about 1,200 people in their New York office, 1,500 in the manufacturing departments and several thousands on the various erection sites. The volume of sales has averaged $70 million over the past 5-6 years. This is the amount passing through their books, but it does not really indicate the value of the plant designed because in many cases only the engineering services are provided.

The process plants division which covers process engineering, mechanical design, purchasing, production and construction employs approximately 50-60 % of the total staff and do approximately 50-60 % of the total volume of business booked by the corporation. The organisation chart of the division is given in figure 13.

The main process and equipment work is carried out by the estimating department, the process engineering department and the project engineering department.

The estimating department consists primarily of mechanical engineers, many of whom have had experience in the drafting and project engineering departments. They are able because of their experience to estimate a price for a given project from relatively sketchy information. This is very important because it is often necessary to produce estimates in the shortest possible time to satisfy the requirements of their clients.

The process engineering group consists of about 50 engineers most of whom are graduate chemical engineers. Their assignment is to develop the process flow sheets giving sizes of fractionating columns, etc., and specifying the duty of heat exchangers, compressors, etc.

The project engineering department converts the process engineering flow sheet into a detailed engineering flow sheet which shows every detail of the plant including the size and specification for each pipeline, the location of control instruments, and the dimensions of the major process equipment. This detailed engineering flow sheet is passed on to the mechanical design and drafting group for the purpose of preparing finished working drawings. To assist the drafting room the project engineering department must present them with data on the mechanical design of each and every part of the plant. There are about 20 project engineers about half of whom are chemical engineers and half mechanical. In addition there are 60-70 equipment specialists mostly mechanical engineers. It is important to note that this

department has separate sections for the preparation of design standards and for operation, i.e. start-up of the finished plant.

The mechanical design and drafting department employs about 300 technical personnel in addition to clerical workers. About 40 % of the number of man-hours put in by the mechanical design and drafting department on a typical process plant is provided by the piping sections.

Every project handled by the corporation passes through the hands of not less than 50 people, even in the case of the smallest projects. The engineering organisation works like a production line.

MECHANICAL
DESIGN
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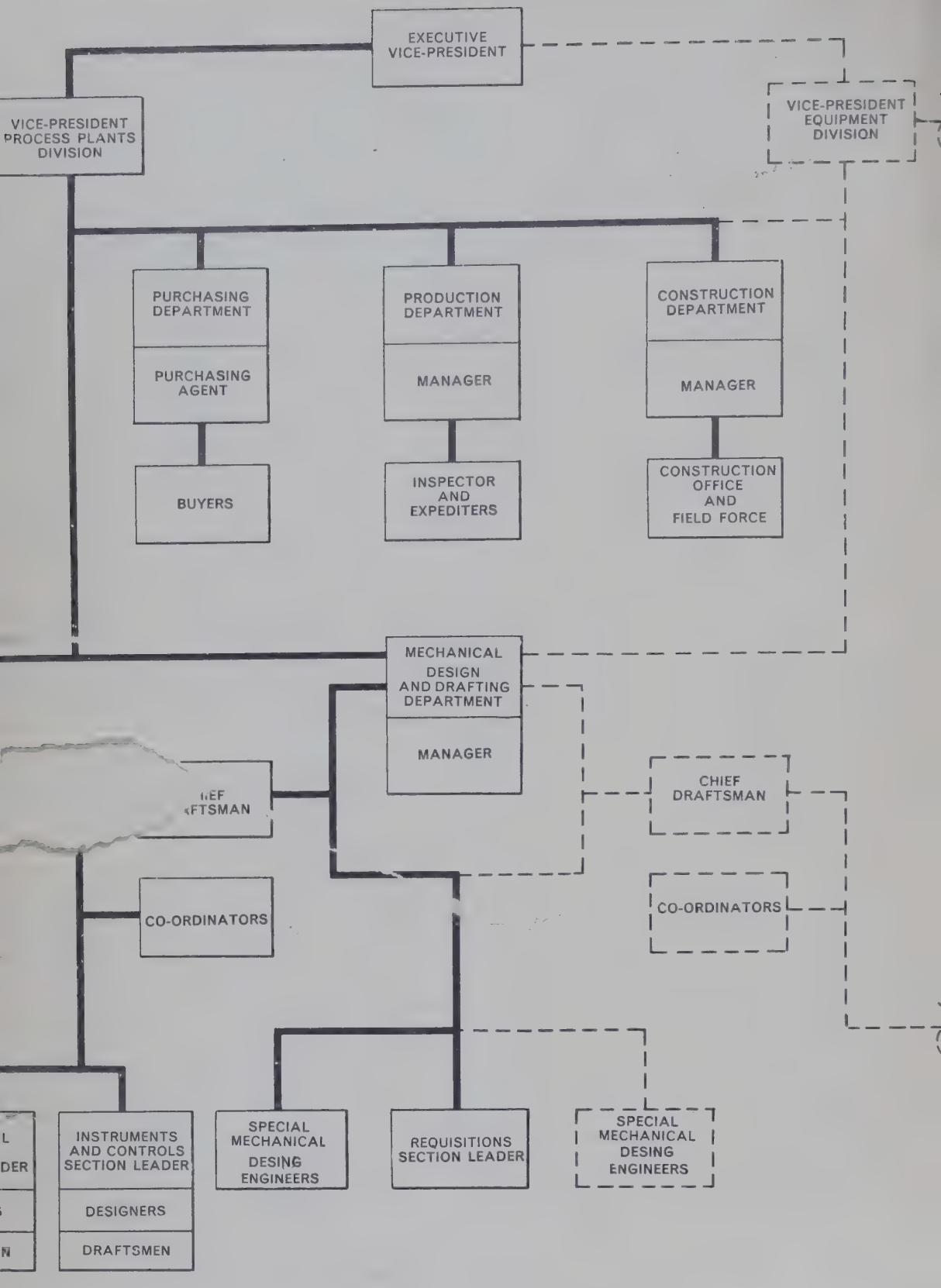


mical engineering firm. Process Plants Division.

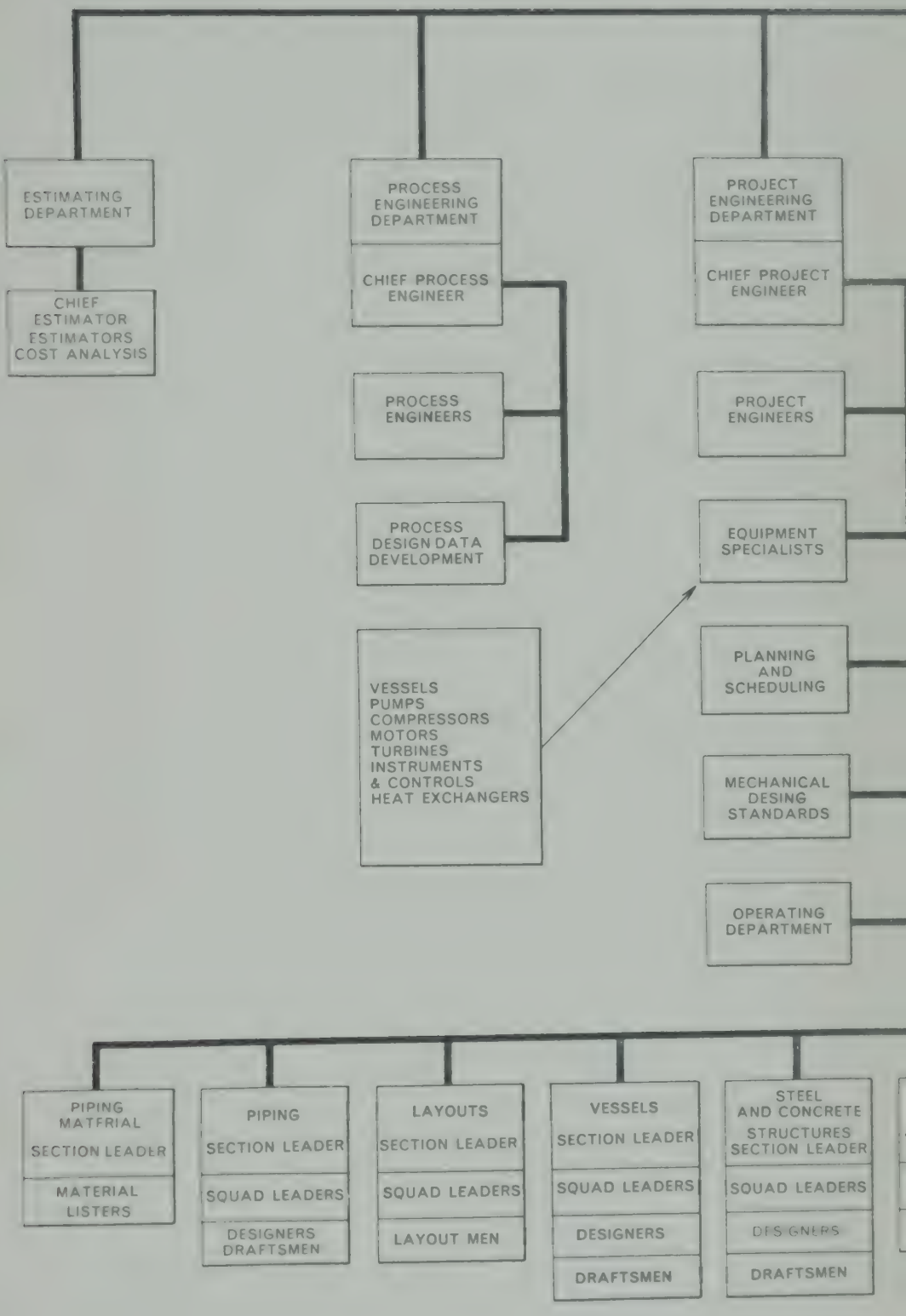


Fig. 13. Organisation Chart o

ANNEX IV

THE ENGINEERING ORGANISATION OF ANOTHER BIG CHEMICAL ENGINEERING FIRM

The general organisation is built up in the usual way with a number of groups each responsible to a vice-president. Among these groups are research and development, engineering construction, general management, manufacturing, legal, finance and the various sales groups. The groups for research and development and for engineering were of particular interest to this Mission and the chart showing these two groups is reproduced in figure 14.

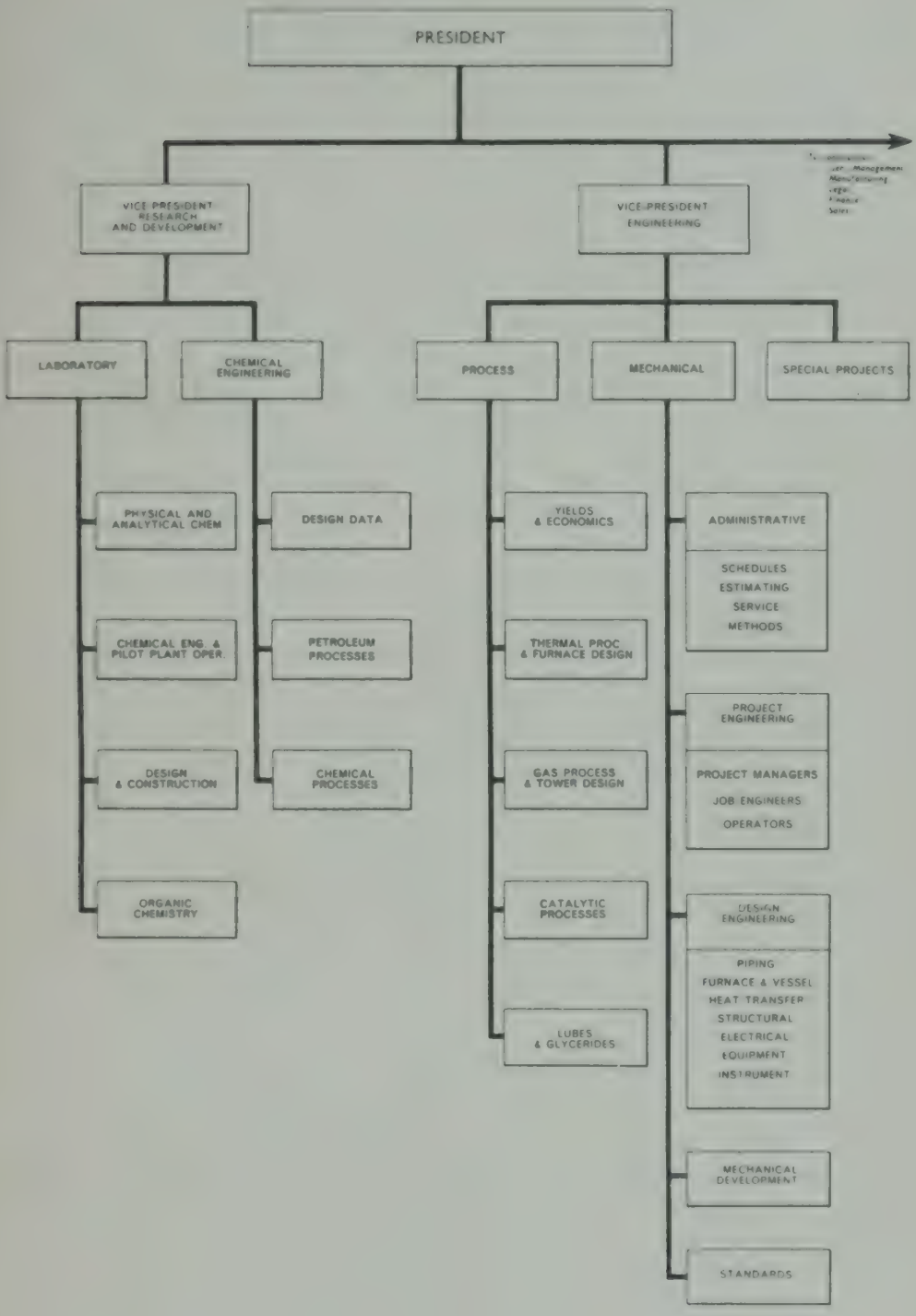
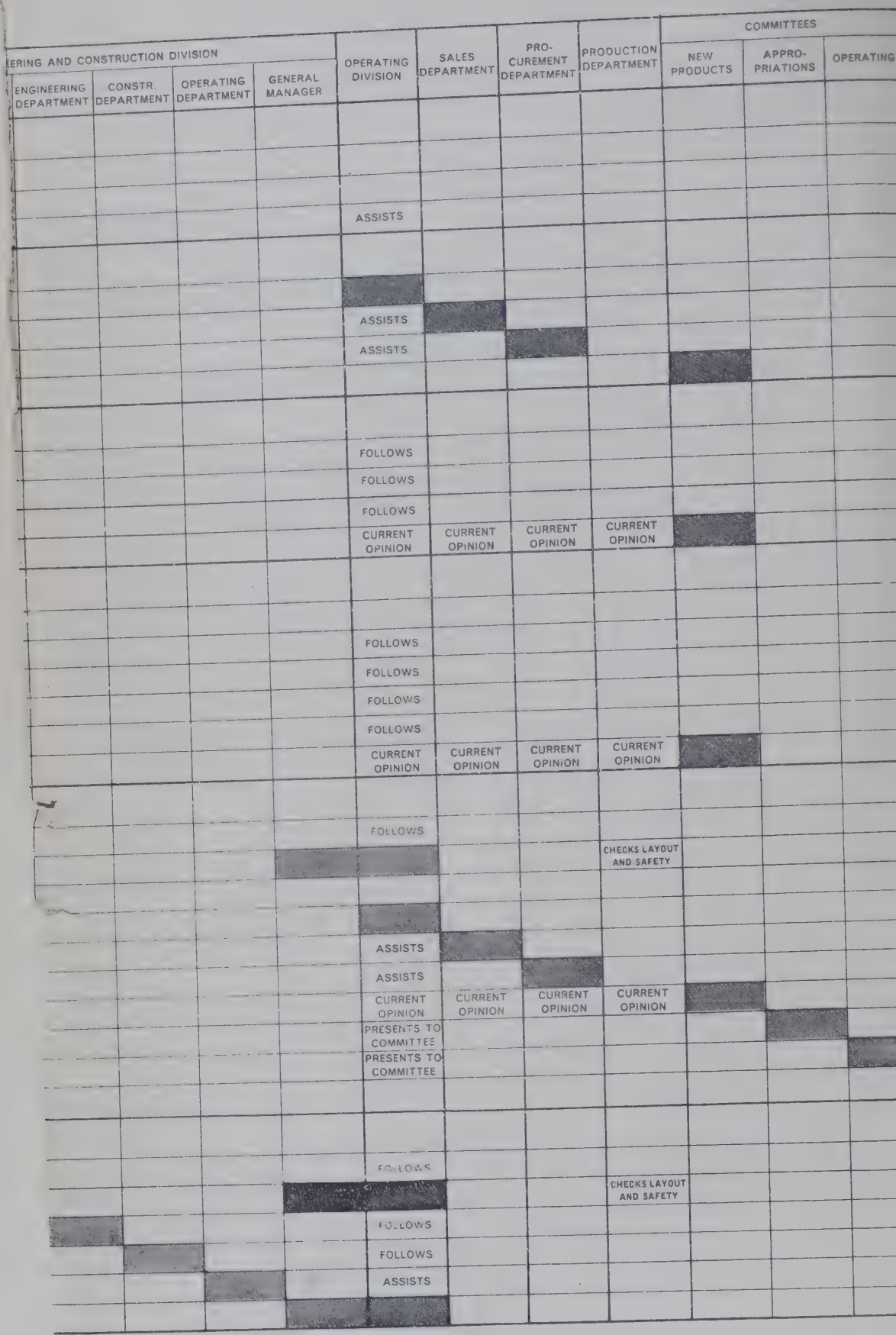


Fig. 14. Organisation Chart of another big chemical engineering firm. (Research, Development + Engineering Division.)

ANNEX V



and commercialisation o fa new process or product.

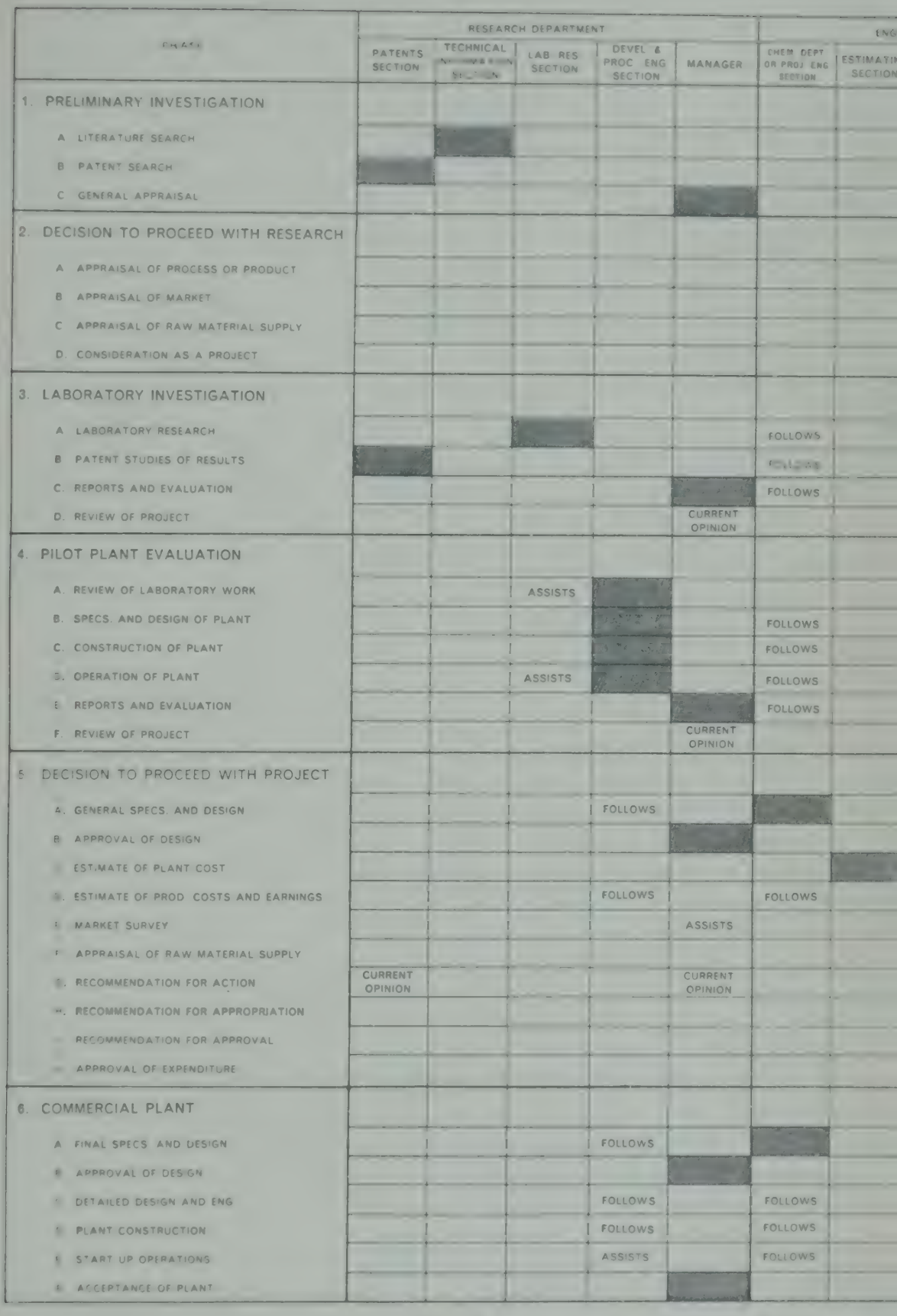


Fig. 15. Flow and sequence of the developme

ANNEX VI

SOME AMERICAN INSTRUMENTS AND CONTROL EQUIPMENT

General

This Annex describes some American instruments and control equipment [1] which, although it will be familiar for the most part to the specialist in instrumentation in all European countries, may not be familiar to many plant engineers and chemists to whom it might be useful.

The equipment described has been selected for one of three reasons, namely :

a) because it is representative of a type,

b) because it possesses interesting design features, or

c) because it indicates a trend in instrument practice in the United States.

It should be remembered that the selection has been made from the equipment which the Mission had the opportunity of seeing, either in the makers' works or on the plant, and that therefore it must not be regarded as a representative selection from the whole field of American instrumentation. At the same time, the reader can safely assume that in the two important parts of the field which include industrial automatic process control and recording instruments, the trends are sufficiently indicated.

It will be remembered that the direction taken by development work during the last few years has been dictated by the following requirements of industry, in which the development of improved and new processes is dependent on the development of new and improved instrumentation :

Greater speed of response of both measuring [2] and control equipment.

Increased sensitivity and consistency.

New instruments for the analysis of plant materials to give a continuous record of composition on the plant.

Reduction of the panel space required for mounting instruments in the control room.

Means for facilitating the work of the operator in the control room.

These requirements have led to the following trends, of which the equipment selected for description below is thought to be typical :

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1. *Controlled condition* : The physical quantity or condition of the plant that it is the purpose of the system to control.

2. *Measuring unit* : The unit comprising those elements (detecting element and measuring element) that ascertain the value of the controlled condition.

The development of detecting elements [1] and indicators and recorders with high speed of response and of compact, robust control units designed for installation on the plant itself as near as possible to the detecting element associated with it.
As an alternative to placing the control unit on the plant, the development of pneumatic transmitters and large capacity pneumatic boosters, to decrease the time lag in transmission of signals [2] between detecting element, measuring element, control unit and regulating unit.
Continuous attention to increasing detecting element speed of response.
Development of new methods, some of which are described below, for continuous plant analysis of process materials.
Production of whole new ranges of miniature instruments to save panel space.
The use of graphic panels.

Automatic process control equipment

It appeared that pneumatic equipment is used almost universally on large chemical plants whenever control is effected by means of valves in a liquid or gas line, except in special instances, e.g. where large electric screw-down valves are necessary owing to the large forces involved at high pressure. That there is no marked tendency to change over to electric control equipment, in spite of its obvious advantages from the point of view of eliminating transmission lags, is no doubt due to two factors : namely, the immunity of pneumatic systems to fire and explosion hazards and the absence of any design of electrically operated valves which can compete with the air operated valves on economic grounds.

Automatic control nomenclature

One of the greatest difficulties in the discussion of automatic control equipment arises from the different nomenclature employed in different countries and indeed among engineers in the same country. Therefore, in order to ensure that the terms used in the following text are understood, the terminology recommended by the British Standards Institution has been adopted. The terms used are defined in the extracts from the B.S.I. Glossary of Terms [3].

The basic principles of design of pneumatic process control equipment

The majority of pneumatic controllers in the United States in chemical plants are designed to give proportional action [4] alone, or proportional action combined with either or both of two other actions, namely, integral and derivative actions.

---

1. *Detecting element :* That part of the measuring unit that responds directly to the value of the controlled condition.
2. *Signal :* The physical quantity by which one part of the control system influences another.
3. See p. 189 *a*).
4. *Proportional action :* A control action varying directly with the deviation.

The action of a *proportional* action controller can be expressed by the equation

$$V = -K_1 \theta$$

where V is the controller output pressure to the regulating unit[1] θ is the deviation[2] from desired value[3], and K_1 is the proportional action factor.

Integral action[4] is expressed by the equation

$$V = -K_0 \int \theta dt$$

where K_0 is the integral action factor.

Integral action, as can be seen from the equation, continues to move the regulating unit until the deviation is reduced to zero. It can therefore be used to avoid " offset[5] " which is bound to appear if proportional action is used alone and which becomes more serious as the proportional band width increases.

Derivative action[6] is expressed by the equation

$$V = -K_2 \frac{d\theta}{dt}$$

where K_2 is the derivative action factor.

Derivative action can be used to make possible the use of a narrower proportional band (and so to avoid perhaps the necessity for using integral action) or to prevent " overshoot " due to rapid changes in the plant conditions.

A controller which employs all three actions defined above will thus give an output pressure to the regulating unit, determined by the equation

$$V = -K_1 \theta - K_0 \int \theta dt - K_2 \frac{d\theta}{dt}$$

If the regulating unit produces an effect on the process, such that the " potential correction[7] " [(H)] is proportional to the change in controller

---

1. *Regulating unit* : The unit comprising those elements that adjust the physical quantity on which the controlled condition depends.

2. *Deviation* : The difference between the instantaneous value of the controlled condition and the desired value. A positive (+) sign is given to the deviation when the value of the controlled condition is greater than the desired value, a negative (—) sign when it is less.

3. *Desired value (index value)* : The value of the controlled condition to which the automatic control mechanism is adjusted. In process control, the desired value may be fixed or it may be varied by an external agent.

4. *Integral action* : A control action that changes at a rate which varies directly with the deviation. From this it follows that the control action varies directly as the time-integral of the deviation.

5. *Offset* : Sustained departure of the control point from the desired value.

6. *Derivative action* : A control action varying directly with the rate at which the deviation changes. This should strictly be called " first derivative action " but the word " first " is usually omitted.

7. *Potential correction* : The instantaneous difference between the potential value and the control point. It is a measure of the corrective influence applied to the process as the result of the adjustment of the regulating unit by the controller.

output (V), then we can rewrite the equation for three action control as

$$(H) = -\mu\theta - \gamma\int\theta dt - \rho\frac{d\theta}{dt}$$

$$(H) = -\mu\left(R\frac{d\theta}{dt} + \theta + \frac{\lambda}{S}\int\theta dt\right)$$

where μ, ρ and γ are the proportional, derivative and integral control factors respectively, and R, S are the derivative and integral action times respectively.

All the pneumatic process controllers in wide use in the United States are designed to give, with their associated measuring and regulating units, control action defined by one of the above equations or modifications of these equations. It should be noted that it is by no means advisable to employ all three actions in every application.

Method of generation of the control action

The controllers illustrated in figures 16 to 20 and 39 to 40 all employ the same basic principles [1] for generating wide band proportional control action; namely, to vary the separation of a nozzle and some obstruction [2] in front of it by an amount proportional to the deviation from the desired value. Such variation causes a proportional change in pressure upstream of the nozzle, which is applied through a relay valve to the regulating unit. Since a variation of this pressure from O to the full air supply pressure is caused by a movement between nozzle and obstruction of perhaps only 0.001 in. or less, this will give " narrow band " proportional control action. In order to provide " wide band " action a feed-back system is used to decrease the " sensitivity " of the controller.

Integral and derivative actions are generated by restrictor and capacity systems with provision for varying their time constant. They are added to the proportional action via the feed-back action.

Figure 16 shows a very much simplified schematic diagram of a typical three action controller of the established panel mounted design. In such a controller, the proportional band width will be determined by the ratio a; b; the integral action time by the time constant of the integral action restrictor and associated capacity of bellows (B); the derivative action time will similarly be determined by the time constant of the derivative action restrictor and its associated capacity (C).

Some new automatic controllers

The new automatic controllers are those which have been designed either for mounting on miniature or graphic panels, or for mounting on the plant near the detecting element. The latter type requires provision for transmitting to the control room either the measured value or the deviation from desired value. In the control room a corresponding unit must be provided for the remote setting of desired value and indication or recording of the transmitted signal.

The controllers for line mounting differ in principle of design from

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1. See p. 189 *b*).
2. Usually called the " flapper ".

the large panel mounting instruments previously available. Both designs are therefore illustrated in figures 18 to 20 and 39 to 46.

Foxboro " Consotrol " controller

Figure 39 shows a front view of the new Foxboro " miniature " controller, which is designed for mounting on one of the new miniature or graphic panels, such as that shown in figure 40.

The basic design of this new controller is exactly the same as that of its predecessor, the Model 40, which is shown schematically in figure 17.

This controller shows the trend towards miniaturisation, but it should be noted that it is designed for panel mounting. In order to eliminate the effect of transmission lags from measuring instruments and to regulating units (with large capacity diaphragm heads), the makers have developed high speed transmitters and boosters[1].

The overall dimensions of the controller illustrated in figure 39 are 7.11/16 × 3.3/16 in.

Honeywell-Brown " C.I.C. " and " Tel-O-Set " controllers

Honeywell-Brown have developed both a miniature control unit for panel mounting and a " line mounting " unit. Photographs of these two units, known as the " C.I.C. " and the " Tel-O-Set " control units respectively, are shown in figures 42 and 43.

The basic design of the " C.I.C. " unit is exactly the same in principle as that of the well established " Air-O-Line " unit, which is shown in figure 18.

A schematic diagram showing the operation of the " Tel-O-Set " control unit is shown in figure 19.

Figures 44 and 45 show " C.I.C. " units and the " Tel-O-Set " receiver indicator and remote setting unit mounted on graphic panels. It will be noticed that the " C.I.C. " units are mounted below the graphic panel itself, which can therefore be made smaller and flexible to provide for changes in the measuring system at a later date.

It is interesting to note that the " Tel-O-Set " model shown in figure 42 is designed for flow control, based on the " dry cell " type flow meter, and is provided with proportional plus integral actions only. The " dry cell " has a high speed of response and the designers, rightly or wrongly, have decided that these two actions give the best control characteristics with this detecting element.

Taylor " Tri-Act " control unit

This control unit is a new development, of which design details are not available. Unlike the Taylor " Fulscope " controller, designed for panel mounting (*fig.* 20), this unit is constructed for line mounting. Its compact and robust construction can be seen from the photograph in figure 46.

The general principle of operation of the " Tri-Act " is shown in figure 46. The unit consists in effect of two sub-units, one of which gives proportional plus derivative action (with a fixed proportional band), while the

1. See p. 189 *c*).

second gives proportional plus integral action (with both actions adjustable). This system is the subject of an interesting paper, which should be consulted for further information[1].

General notes on controller design

The designs given in figures 17 to 21 and 39 to 46 show that the makers are agreed on the necessity for decreasing panel area. On the other hand, they are divided on the best approach to elimination of transmission lags from the control loop. Foxboro keep the control unit in the control room and use high speed transmitters and boosters, Taylor have produced a control unit for line mounting, and Honeywell-Brown have provided both types.

It is also worthy of notice that control units can be made so robust and resistant to the moisture, corrosive gases, etc. found on the plant, that they can be sited on the plant without danger of incurring increased maintenance cost. The continuous air leak from the control unit is of course an advantage in this respect, because it purges the case of the unit with clean air.

Valve positioners

Valve positioners are very commonly used in the United States in applications where accurate and rapid positioning of the valve or other regulating unit is essential. The positioner applies full air pressure to the regulating unit until it is positioned very accurately according to the demand of the controller. An exemple of such a positioner is shown in figure 21.

Regulating unit

The regulating unit of chief interest to chemical plant is the control valve, for which many satisfactory designs have been long available. No basic developments were encountered in the United States, but there has been some considerable improvement in details such as gland packing, etc., which tend to decrease maintenance costs.

The use of " Teflon " as a gland packing material is to be especially noted.

High pressure control valves

The valves shown in figures 22 and 23 may be of interest to those concerned with high pressure plant or pilot plant with very low flow rates. The success of these valves depends on a fine finish for the valve stems and the use of " Teflon " for the gland packings.

Standardisation of overall length

It is encouraging to note that agreement has been reached between the American and British standard authorities on the overall length between flanges of control valves. Control valves of makers working to this agreed

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1. See p. 189 *d*).

standard will therefore be interchangeable without alteration to the pipe line[1].

Fischer and Porter have introduced a range of automatic control valves which are made in two sections to facilitate cleaning (*fig.* 24). The valves can be made with porcelain base and stainless steel trim, and the same type of construction can be followed using plastic components.

Recorders and indicators

Electronic recorders

The galvanometer/chopper bar type of automatic potentiometer recorder, which achieved a high state of development in the United States, now seems to be losing ground rapidly to the new all-electronic recorder. The latter has the advantage of being considerably more rapid in action, of giving a continuous instead of an intermittent record, and of being more sensitive.

The method of operation of the four electronic recorders shown in figures 25 to 28 are shown by the schematic diagrams.

In figure 25 the Honeywell-Brown " Electronik " potentiometer is shown adapted for thermocouple work.

In figure 26 the Bailey " Pyrotron " is given as arranged for use as an impedance bridge. The arrangement shown will measure movements of the transmitter core (C) as small as 5.10^{-6} inches.

The Foxboro " Dynalog ", shown in figure 27, employs an entirely different principle from the recorders shown in figures 25 and 26, and eliminates the slide wire which has always hitherto been a feature of the potentiometric recorder. The " Dynalog " employs a capacity resistance bridge and makes a balance by adjusting the capacity of a variable condenser. The advantage of doing this is that the adjustment is continuous, whereas with the normal slide wire the smallest adjustment which can be made depends on the resistance of one turn of the slide wire, which is normally wound as a small diameter coil.

The " Dynalog " is easily adjusted to make capacity measurements and finds many applications for this purpose, e.g. continuous measurement of rubber sheet thickness.

Multi-point circular chart electronic recorder

The Foxboro Company has designed a multi-point circular chart recorder which employs only one pen arm. This pen arm picks up magnetically pens with different coloured inks, from a holder which rotates so as to receive a pen from the pen arm and deliver a new pen to it. The system is most elegant.

Multi-point pressure recorder

The Foxboro Company have developed a 6-point pressure recorder, for use with remote transmitting measuring units. Unfortunately, no details are available on the design of the pneumatic changeover switch, which is the heart of the instrument. A photograph of the inside of the case is shown in figure 48.

1. See p. 189 *e*).

160 *point recorder for electrical detecting elements*

The Leeds and Northrup " Speedomax " recorder is shown (*fig.* 28) arranged for recording two variables at once. The instrument is used in this way for plotting hysteresis curves, valve characteristics, and in other applications where a rapid plot of two variables is useful.

In the arrangement shown in figure 47 the high speed of the " Speedomax " system is utilised to record 160 points; the whole cycle of recording 160 points is carried out in something less than eleven minutes. In the instrument shown, any individual point can be switched to be recorded continuously; alternatively, any bank or banks of points can be switched in for intermittent recording.

Miniature pressure recorder (for use with transmitters)

The Taylor Company has developed a new miniature type pressure recorder (*fig.* 45 *a*) for mounting on the " graphic " or " miniature " panels. It is designed to record the output of the Taylor transmitters. A panel unit containing 25 of these recorders is shown in figure 53.

Indicators

Although a great number of deflection type galvanometer indicators are still used with multi-point switch boxes, there is a strong tendency to install self-balancing potentiometer indicators on new plants. These indicators are basically the same as the electronic potentiometers mentioned above. The economic justification for installing what is an expensive type of indicator is the saving of operator's time in logging a large number of points and also, it was stated, the lower maintenance cost compared with the galvanometer type indicators.

Dialling system for multi-point electrical recording or indication

Modern plants are apt to employ very large numbers of detecting elements for the measurement of the various physical conditions in the plant. Examples of plants containing more than 1,000 such elements were quoted, and it was said that the limit had been reached to the use of switch boxes and indicators, both from the point of view of the space they occupy and that of the operator. The problems presented by the large number and length of leads from control room to the detecting elements on the plant are also becoming prohibitive.

A telephone dialling system has been developed by the Sun Oil Company, as shown in figure 36, to overcome this difficulty. The system used for a maximum of 1,000 detecting elements is shown. It was stated that several such systems have now been installed and are working very satisfactorily. Considerable ingenuity has been displayed in making the system easy to operate without error and the original paper describing it is recommended as one of particular interest[1].

Detecting elements

Temperature

Continued development of detecting elements of all kinds is proceeding with the object of obtaining the greatest possible consistency, speed of

1. See p. 189 *f*).

response and robustness. An example of a new high speed temperature detecting (platinum resistance type) element is shown in figure 32.

In figures 49 and 50 are shown detecting elements for measuring comparatively low surface temperatures. These elements have proved useful in service although they both depend for their consistency on constant emissivity of the surface examined. No element was seen which gives an accurate temperature independent of the surface emissivity and there was nothing to suggest that development work is proceeding towards designing one.

In connection with the stress laid on reduction of transmission lags, the transmitter in figure 29 is of interest. It is designed to transmit the reading of a liquid, gas or vapour filled thermometer element to a distant recorder or controller. The novel design feature is that a derivative action is incorporated in the transmitter, with the object of " anticipating " the change of temperature of the detecting element. It should be noted that, while this device can reduce the effect of transmission lags in temperature measurement, it cannot normally entirely eliminate it.

Flow

The *Variable Area type flowmeter*, or, as it is often known, the *Rotameter*, has been considerably developed during the past few years and is now available for remote recording and indicating and for remote control. Apart from its main duty of measuring the flow of corrosive or dirty fluids which give difficulty with orifice plates, it is also used in preference to the orifice plate for metering clean fluids in some installations.

The Rotameter is also used for giving a continuous record of viscosity of fluids, using the arrangement shown diagrammatically in figure 30.

The diaphragm operated, force balance type of flowmeter is a comparatively new development, which eliminates the large time lags associated with the mercury filled manometer flowmeter. It is also useful in plants where mercury for one reason or another cannot be employed.

An instrument made by the Foxboro Company is shown in figure 51. The high and low pressure tappings from the orifice plate are led to either side of the diaphragm. The force exerted on the diaphragm by the differential pressure is measured by a pneumatic force balance system, which maintains the diaphragm always in the same position. Overload protection is given by the convolutions in the diaphragm housing, which exactly match the convolutions on the diaphragm itself.

The instrument is also supplied with electric transmission; in this instance the displacement of the diaphragm is measured by means of a strain gauge.

Pressure

The Bourdon type pressure gauge is used almost universally in the range for which it is suitable. For measurements below this range a variety of diaphragm and bellows operated pressure gauges have been developed and, with the advent of the use of very low pressures for vacuum distillation, etc., and the processes concerned with the utilisation of atomic energy, the Pirani gauge has been developed into a reliable plant instrument. Descriptions of these instruments have appeared in the literature.

No information was obtained on any new developments of pressure gauges to measure very high pressures, of the order of thousands of atmospheres.

Level

Torque tube instruments

The main problem in liquid level measurement is usually that of designing a friction-free mechanism for transmitting the movement of a float through the walls of the vessel in which the liquid is contained. An elegant, and successful, method of overcoming this difficulty is given by the torque tube. Instruments based on this method are very popular, especially because they are easily adapted for use at high pressures and contain no glands. The schematic diagram in figure 31 shows the design of one such instrument.

Radiation absorption method

An interesting method of determining the level of " boiling beds " (as used in fluid catalyst work) at high temperatures, was described during a visit to the Sun Oil Company, Marcus Hook, Philadelphia. It depends on the absorption of radiation from two sources of radioactive material, placed outside the vessel and, say, at the bottom and half-way up, respectively, as measured by a detecting element placed diametrically opposite the two sources, again outside the vessel, and above the level of the boiling bed. Details of the system were not obtained, but the principle is clearly interesting[1].

Magnetic follower type meter

A simple level indicator which avoids glands is shown in figure 33.

Thickness measurement

There is considerable interest in the United States in the measurement of the thickness of vessel and pipe walls, etc., for inspection purposes, and also in the continuous measurement of thickness of metallic and non-metallic sheet during its manufacture. In particular, methods depending on the absorption or back-scattering of radiation from radioactive isotopes are receiving attention. " Tracer Lab. Inc. ", which specialises in producing equipment for measuring radioactive isotope radiation and equipment for handling the isotopes, has developed a continuous thickness meter based on the absorption of beta-rays from a radioactive isotope source. The instrument is claimed to give sufficient consistency to make it a valuable plant tool.

An instrument based on the absorption of X-rays is manufactured by both the General Electric Company and the Sheffield Company.

Analysis

The analysis of plant fluids is becoming increasingly important and new instruments are constantly being developed to give a continuous record

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1. See p. 189 *g*).

of the concentrations of particular components of plant fluids. The instruments of this type which are of greatest importance, because most generally applicable, are those depending on the absorption of ultra-violet or infra-red radiation. Again, of these two methods, the infra-red absorption method is the more important[1].

Radiation absorption type analysers

The American instruments illustrated differ from those available in Europe, in being based on the Pfund principle instead of that developed by Luft in Germany. The relative merits of the two systems are difficult to assess in general terms. However, it is quite clear that each has merits in different applications. The American type instruments are said to have been successful in plant use, but none were seen in operation.

An instrument described during a visit to the Leeds and Northrup Company is shown diagrammatically in figure 34. The instrument is mounted in an insulated, temperature controlled case which can accommodate sample cells from 1 inch to 9 inches long. Using the 9 inch cell, full-scale deflection is given for 0.1 % CO_2. This gives an idea of the sensitivity of the instrument, which has been used mostly in oil refineries and for the control of CO_2 atmosphere in heat treatment furnaces.

An instrument of different design made by Baird Associates is shown diagrammatically in figure 35. Descriptions of other infra-red gas analysers will be found in the literature.

The ultra-violet gas analysers are used mostly for detection of mercury vapour in the atmosphere and for determining chlorine concentrations.

pH measurement

In view of the great difficulties which have been experienced in the measurement of pH in plant conditions, it may be useful to record some of the points made in a discussion during the visit to Leeds and Northrup, which has specialised in pH measurement.

The discussion was confined to glass electrodes. Dr. Purley has developed a series of glass compositions for use at elevated temperatures and in the presence of high sodium ion concentrations. Electrodes have been produced which operate successfully at 107°C., which is almost the boiling point of the KCl salt bridge in the internal calomel cell. These electrodes have a high resistance at lower temperatures (e.g. 500 megohms at 50°C).

However, it was agreed that more trouble is caused by electrical leakage at the electrodes than by unsuitable glass compositions. To overcome this difficulty, Leeds and Northrup have designed a flexible electrical connection to the internal calomel half cells of the glass electrode, which is completely insulated by a semi-flexible plastic moulding, and with this insulation such an electrode will work satisfactorily even when the connection between lead and electrode is submerged in boiling water. The electrode stem itself is electrically shielded by a thin metallic layer on the outside of the glass stem. This layer is so thin as to be almost invisible.

Hair crack type junctions are used for the calomel reference cells which have plastic covered connections to the glass electrodes and which are arranged so that the salt bridge can be renewed without disconnecting the electrical connections.

1. See p. 189 *h*) and *i*).

It was suggested that, since in many pH control applications it is necessary to use derivative action, the continuously balanced electronic type potentiometer is to be recommended when pH measurement is used as a basis for control. This recommendation is obviously sound, but experience has shown that the mechanical/galvanometer type potentiometer can be used satisfactorily for pH measurement in the majority of control applications.

Control rooms

Mention has already been made of the tendency to use miniature instruments on the panels in the control room, so as to economise in panel space. "Graphic" panels have also been mentioned. Some examples of both miniature and graphic panels are shown in figures 52 to 54. Unfortunately much of the effect of the line diagram on the graphic panels is lost because the photographs are not reproduced in colour.

There is a continuous argument among instrument engineers in the United States with regard to the advantages of these two types of panel, but it seems to be generally agreed that the use of miniature instruments is desirable. Not only do they reduce the panel space necessary, but they also facilitate the work of the operator because he is able to see all the instruments on the panel without walking up and down to examine them individually.

It must be remembered, when the economics of using miniature instruments is considered, that reduction in panel space effects a reduction in the cost of the control room building.

Whether " conventional ", miniature or graphic panels are used, the control room is always made as attractive as possible, at considerable expense. This expense is however only a very small fraction of the total cost of the plant, and it is therefore considered to be economic because of the good psychological effect on those who work in it and all who visit it.

Conclusion

These very brief notes are intended to do no more than indicate some of the interesting instrumentation which is at present available in the United States. It must be stressed again that, although the equipment mentioned is thought to be representative of present practice, it must be regarded only as a sample of what was seen during the Mission's visit.

Information on all the more important points raised in this Annex can be found in the books and papers referred to in the list which is given below.

This report would be incomplete, and of considerably less value to the reader, if attention were not called to the very important fact that equipment equivalent to the majority of that described is either already manufactured in Europe, or will be manufactured in Europe in the near future.

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a) " Glossary of Terms used in Automatic Controlling and Regulating Systems. Part I : Process Control ". Issued by the British Standards Institution.

b) " Principles of Industrial Process Control ", D.P. Eckman. John Wiley & Sons Inc., N.Y., 1945.
" Industrial Instruments for Measurement and Control ", T.J. Rhodes. McGraw-Hill Book Company, 1941.

c) " Pneumatic Transmission Lag ", Mead Bradner.
" Factors in Precise Control of Liquid Flow ", Allan R. Catheron.

d) " A New Concept on Automatic Control ", R.E. Clarridge. Instruments, vol. 23, p. 1248.

e) British Standards Specification : Flanged Automatic Control Valves for the Petroleum Industry, Face-to-face Dimensions. B.S. 1655, 1950.

f) " Process Monitoring Systems ", Ed. Grace (Jr). Instruments, vol. 23, p. 1070.

g) " Development of Wide Range Radiation Type Level Control for Houdry Catalytic Cracking Process ", E.J. Grace and O.W. Graham. Instruments, vol. 23, p. 1074.

h) " Selective Infra-red Gas Analyser ", W.G. Fastie and A.H. Pfund. Journal of the Optical Society of America, vol. 37, pp. 762-768.

i) " A New Method of Recording Gas Analysis by Absorption of Infra-red Radiation without Spectral Dispersion ", K.F. Luft. Zeitschrift fûr Technische Physik 5, 1943.

FIGURES 16 — 54

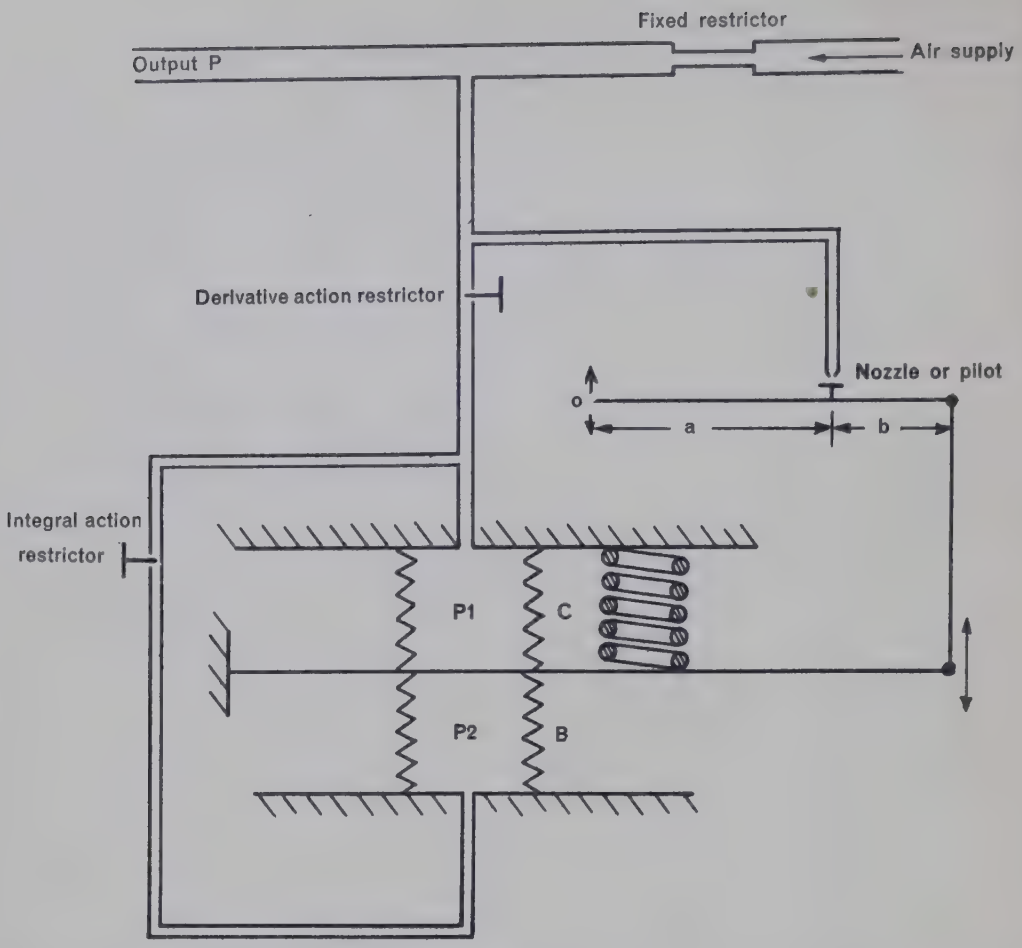


Fig. 16. Schematic diagram to show basic principles of a typical three-action pneumatic controller.

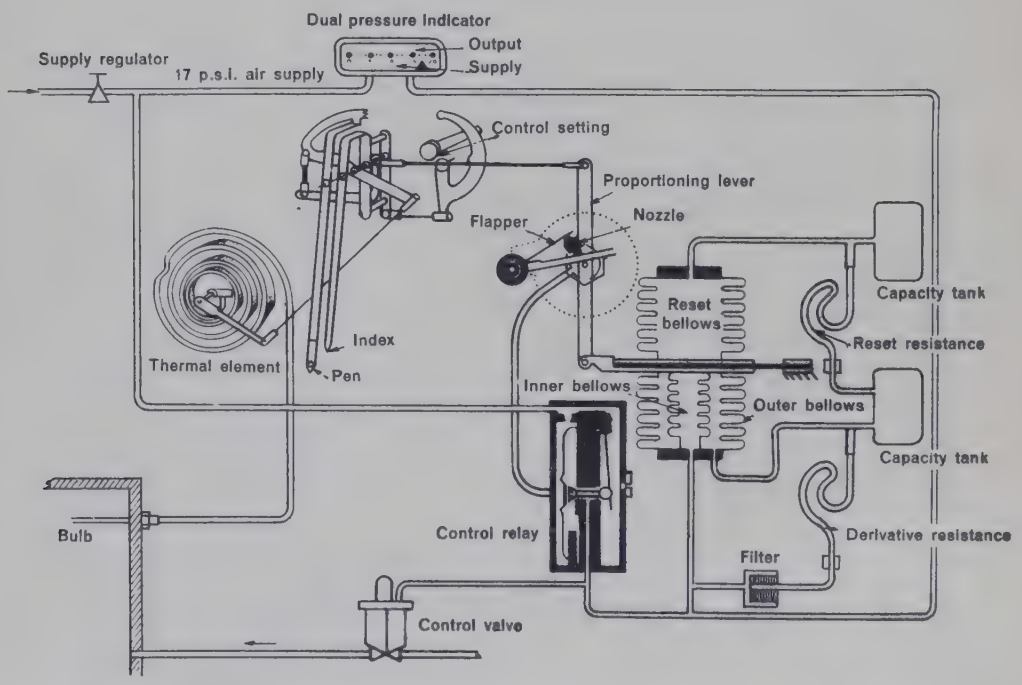


Fig. 17. Schematic diagram of Foxboro Model 40 controller with hyper reset.

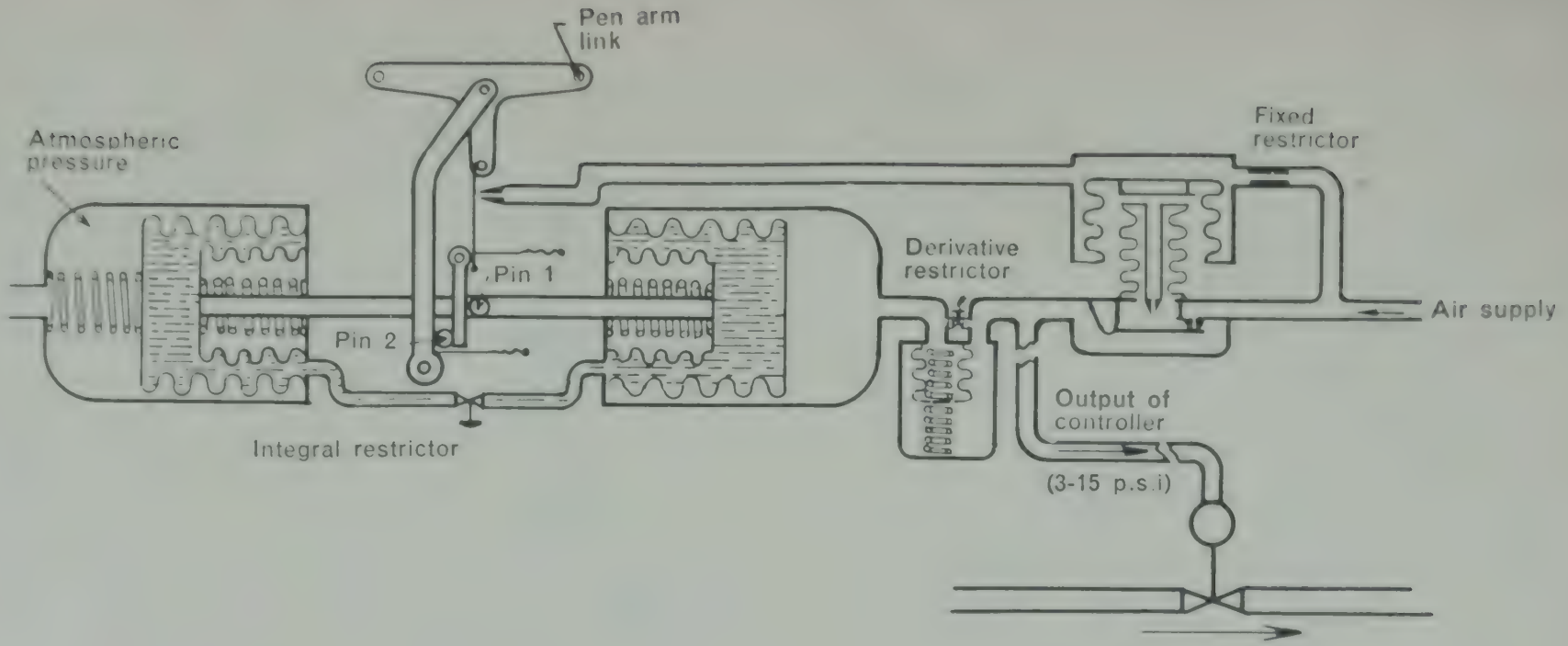


Fig. 18. Schematic diagram of Honeywell-Brown " Air-O-Line " controller.

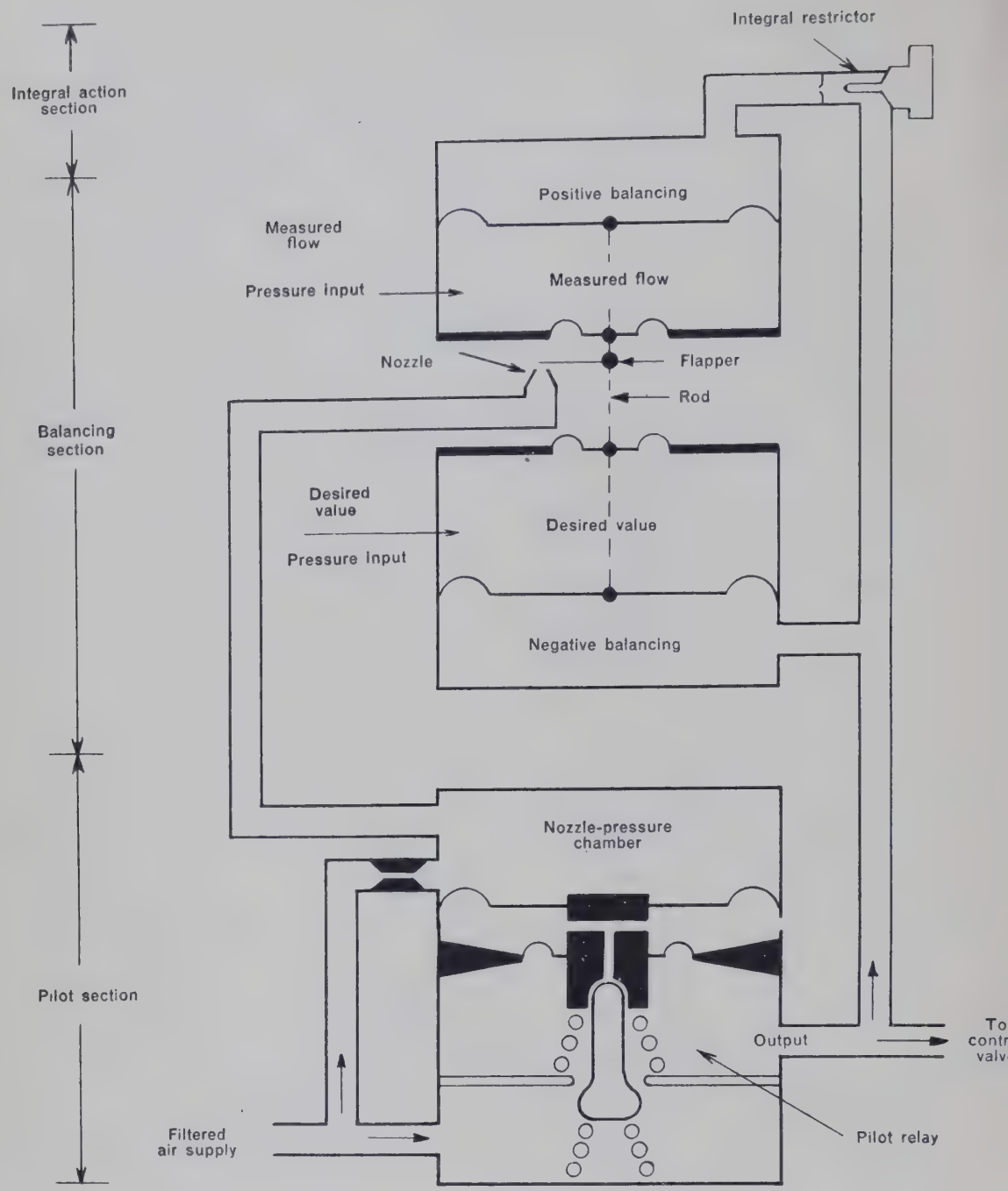


Fig. 19. Schematic diagram of " Tel-O-Set " control unit.

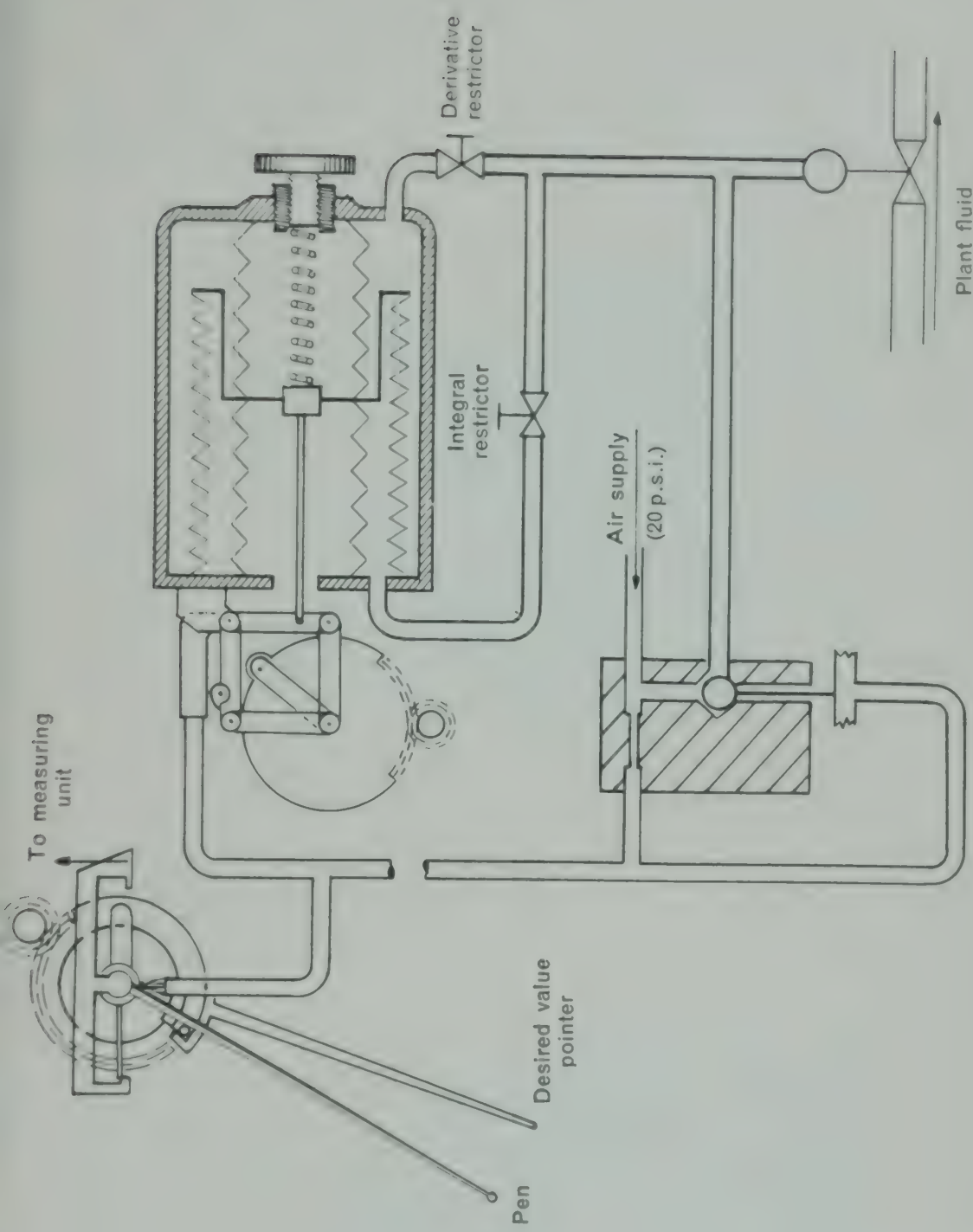
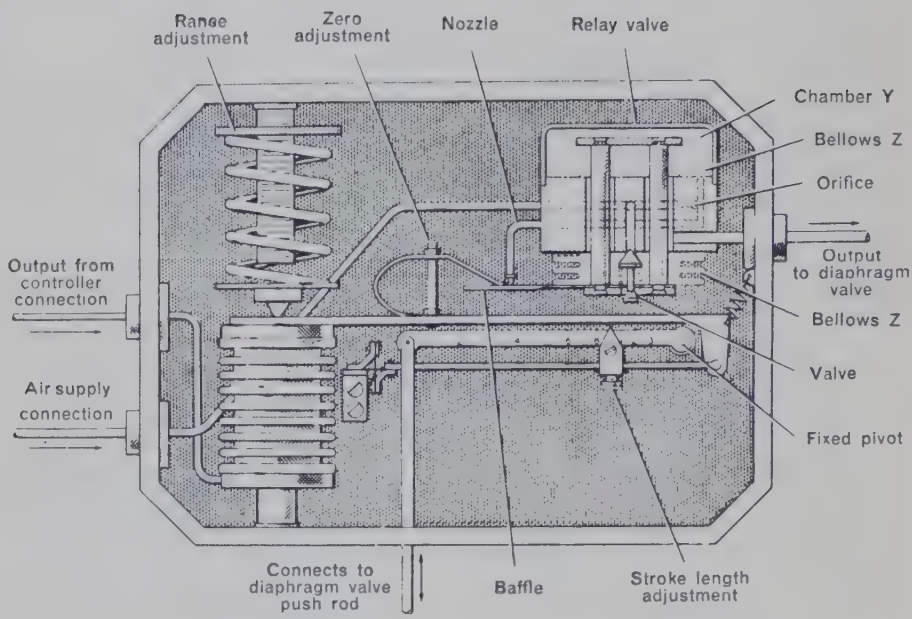


Fig. 20. Schematic diagram of Taylor " Fulscope " controller.



If the controller output should drop when the positioner is in equilibrium the bellows would immediately deflate causing the baffle to move away from the nozzle. The nozzle back pressure decreases, allowing the z bellows to move up due to the decreased pressure in the chamber y. This action closes the supply port of the valve and opens the exhaust port which allows air in the diaphragm motor to be released to atmosphere. As the diaphragm pressure decreases, the push rod connected to the valve stem moves up. Through the lever arrangement, the baffle is moved up by this action, capping the nozzle and modulating the relay output until a condition of equilibrium is again established. By moving the adjustable pivot on the push rod lever arm, the positioner operating range is made to agree with the particular valve stroke required. The positioner operating range may be changed by substituting a different range spring. The positioner operating range may be shifted by turning the range adjusting nut.

Fig. 21. Taylor precisor valve positioner.

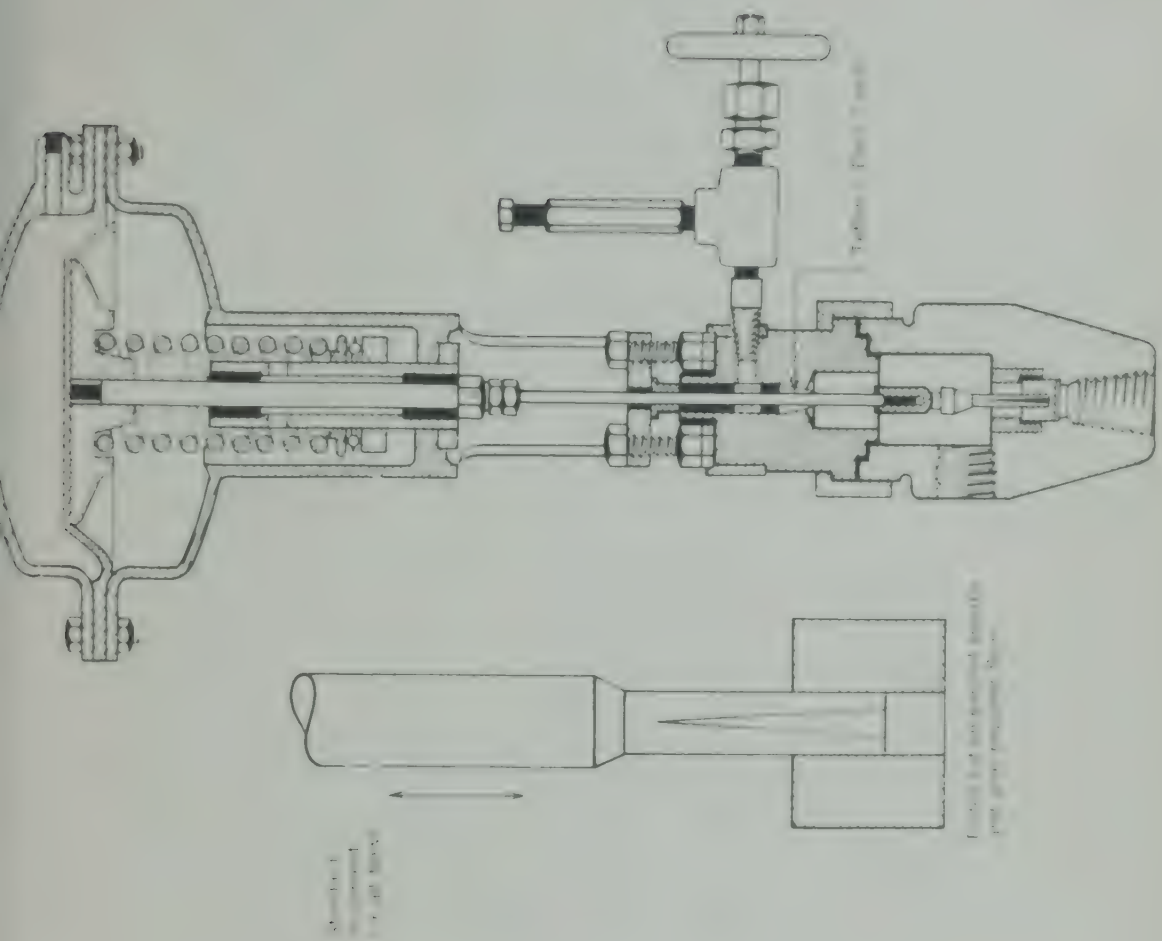


Fig. 22. Hammel Dahl H.P. flow valve.

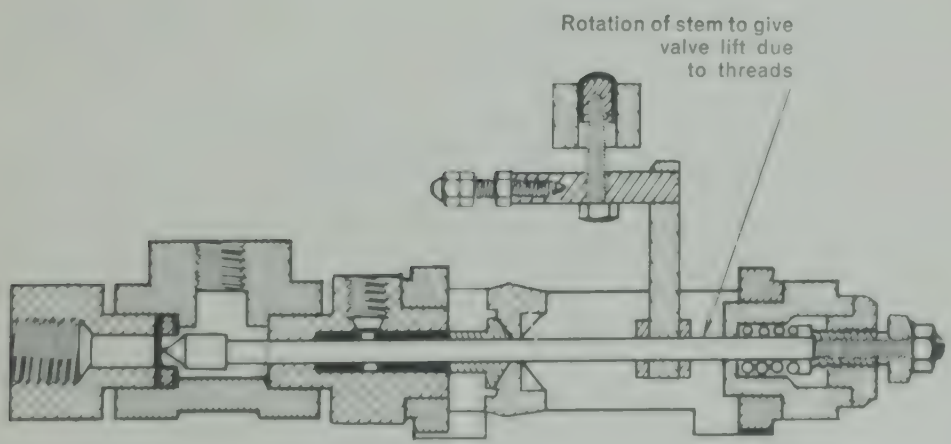


Fig. 23. Fisher Governor H.P. flow valve.

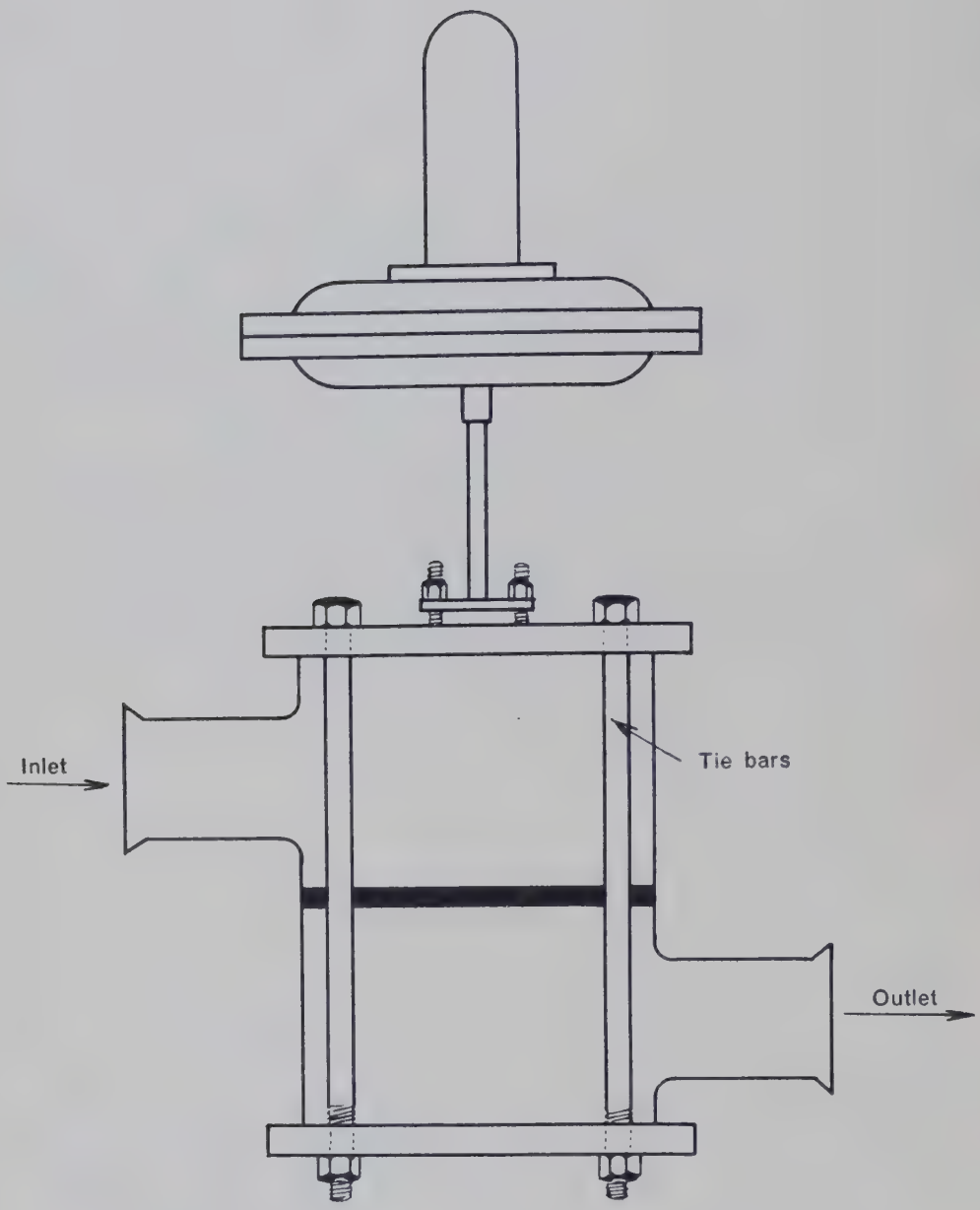


Fig. 24. Fischer and Porter control valve.

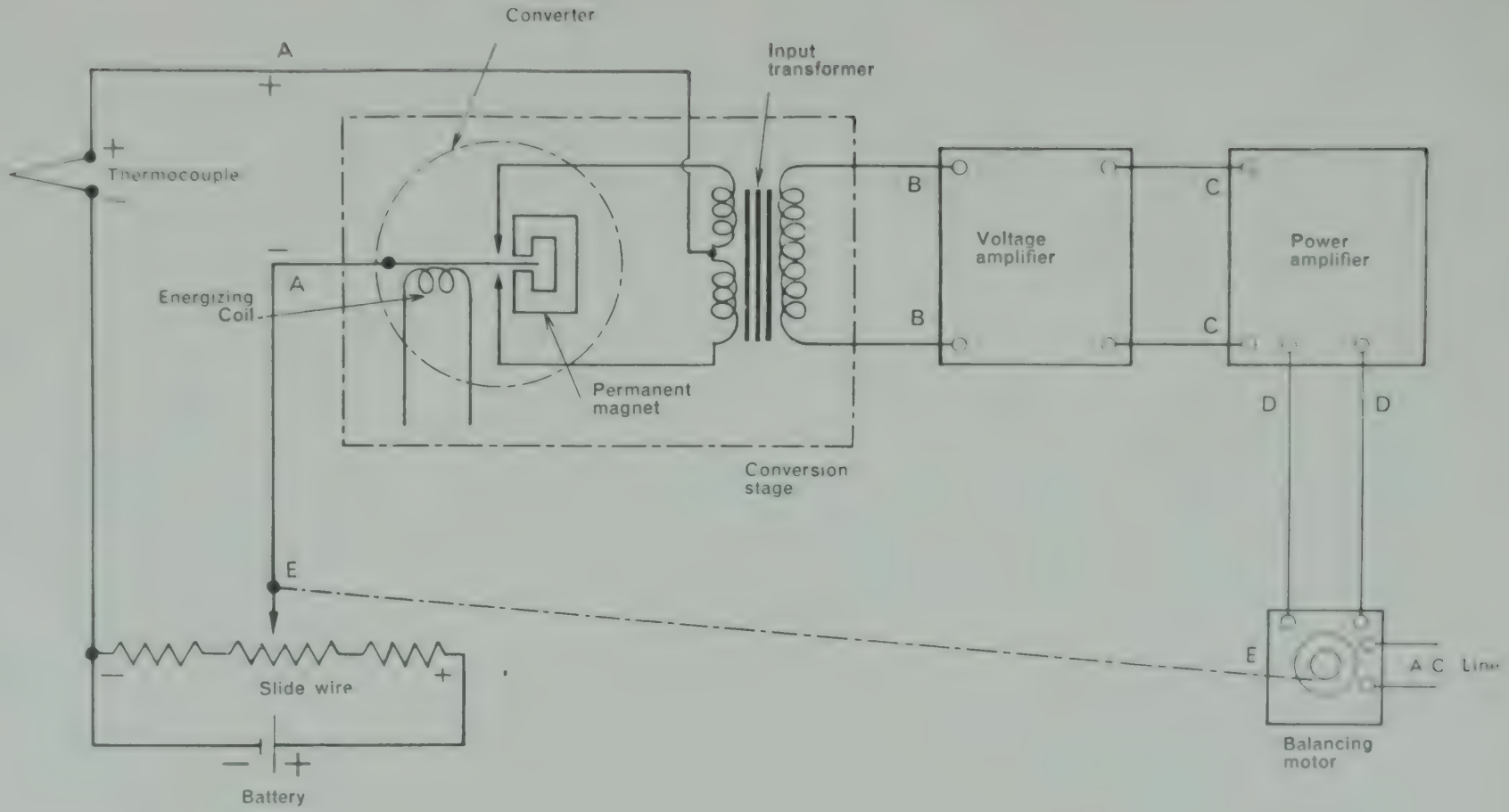


Fig. 25. Schematic diagram of Honeywell-Brown " Electronik " recorder arranged for thermocouple measurements.

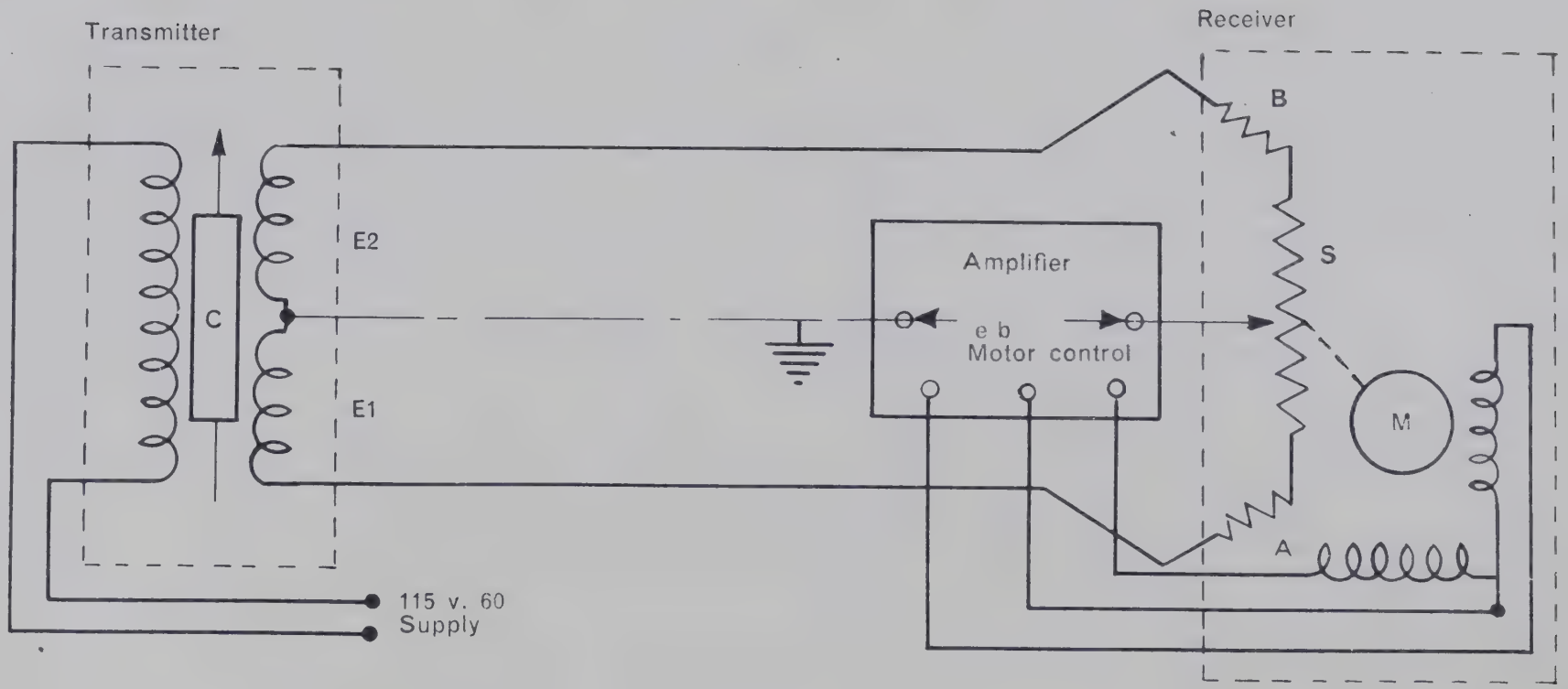


Fig. 26. Schematic diagram of Bailey " Pyrotron " arranged for use as an impedance bridge.

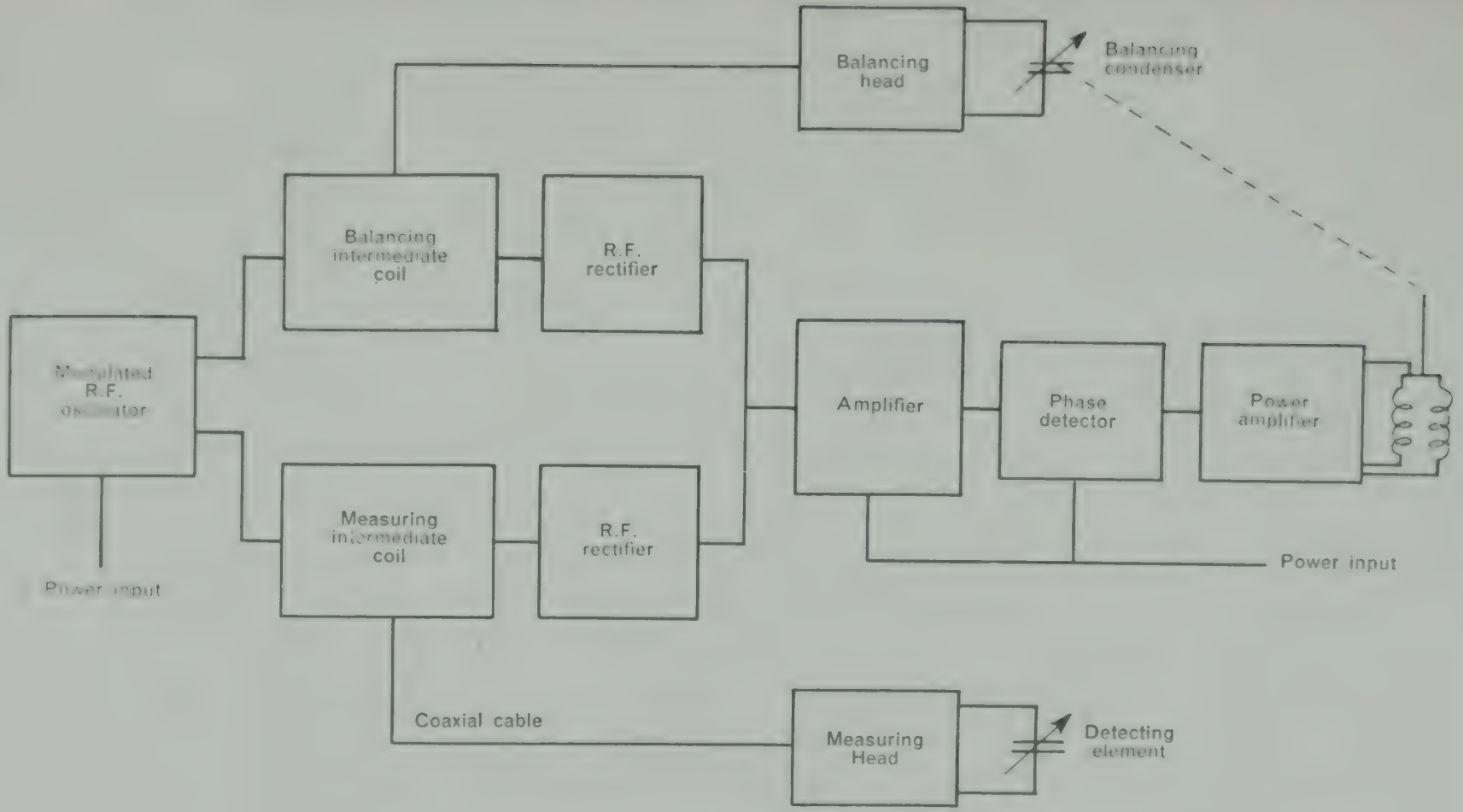


Fig. 27. Schematic diagram of Foxboro " Dynalog " arranged for capacity measurement

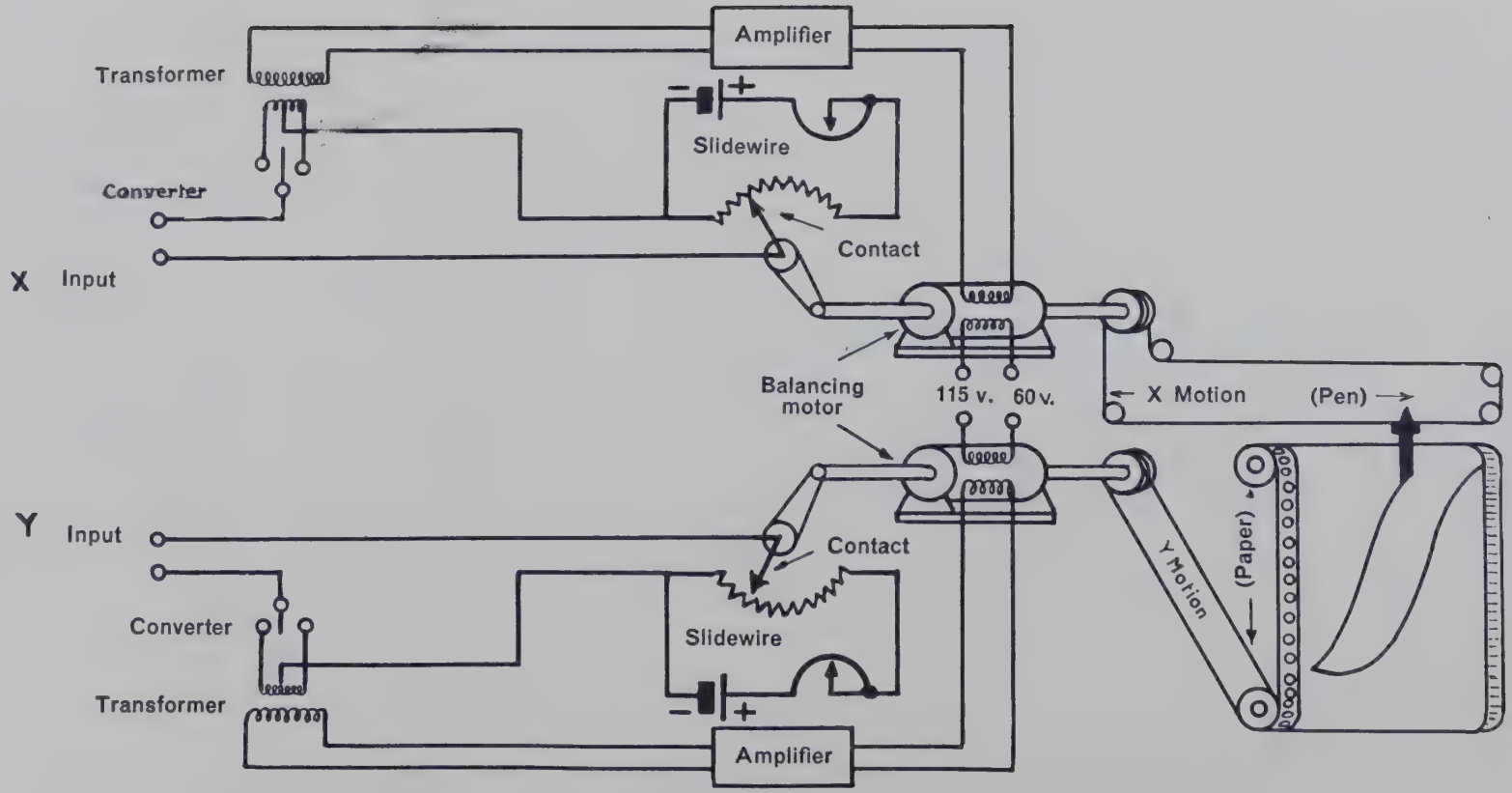


Fig. 28. Schematic diagram of Leeds & Northrup Speedomax arranged for recording two variables simultaneously.

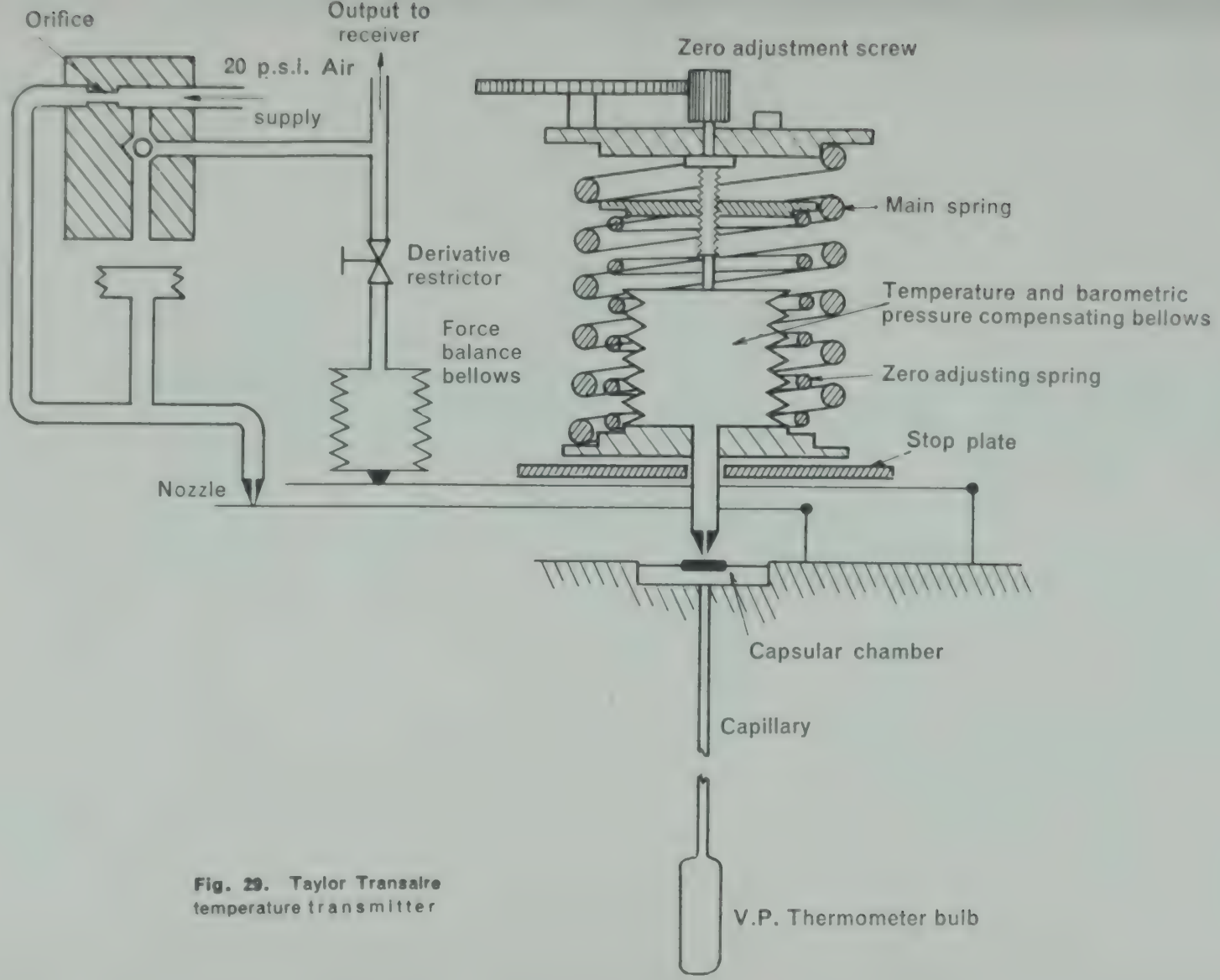


Fig. 29. Taylor Transaire temperature transmitter

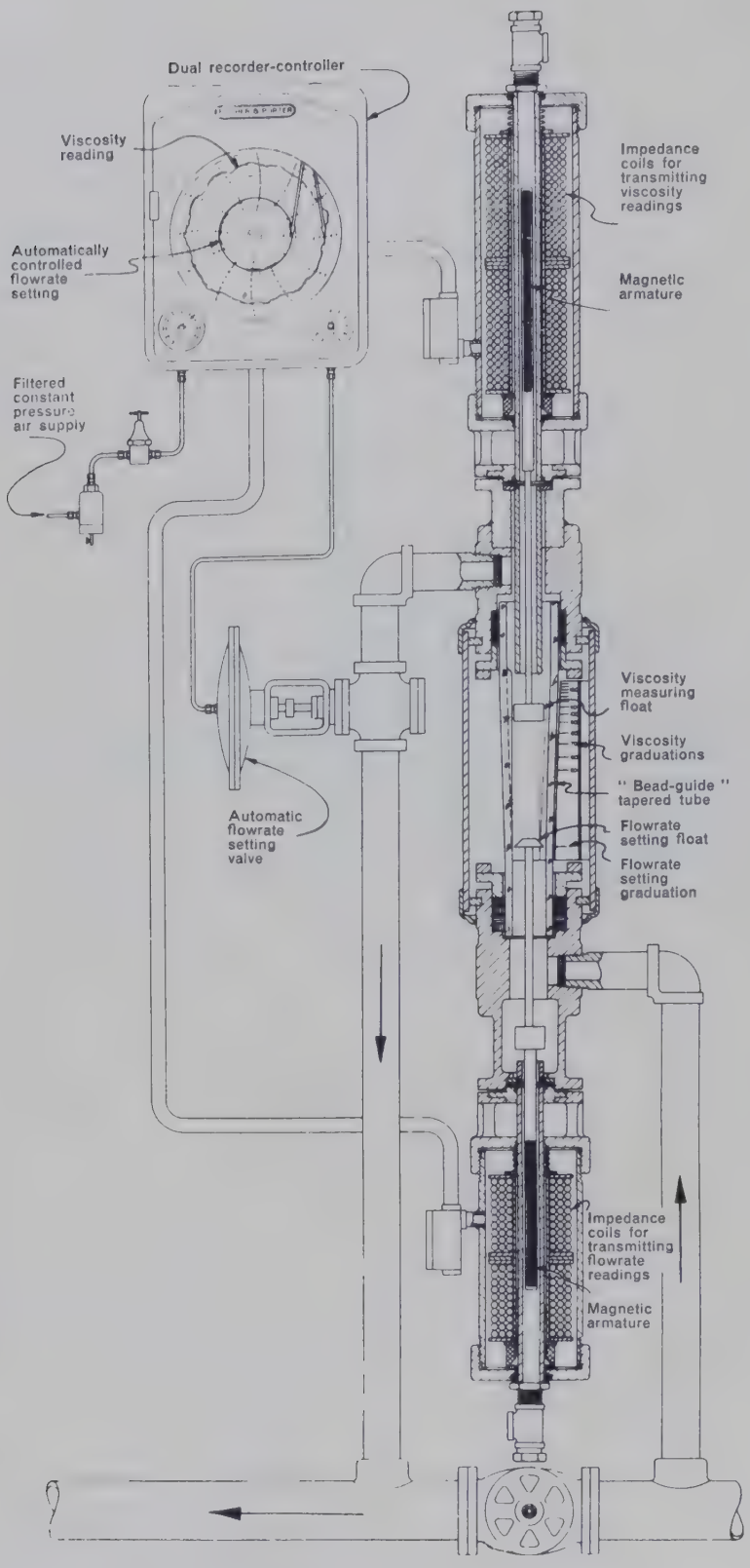


Fig. 30. Fischer & Porter Rotameter for recording viscosity.

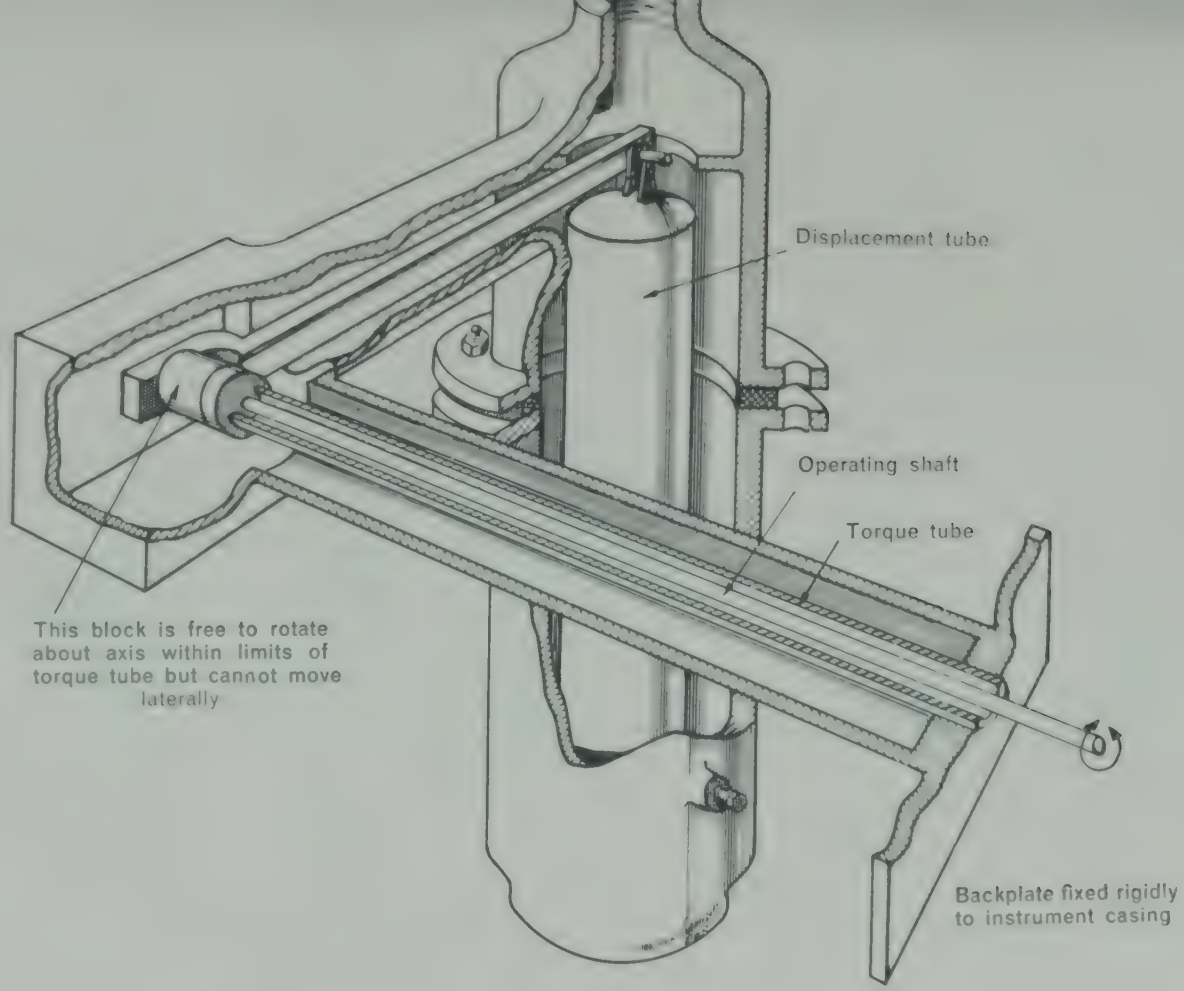

Displacement tube
Operating shaft
Torque tube
This block is free to rotate about axis within limits of torque tube but cannot move laterally
Backplate fixed rigidly to instrument casing

Fig. 31. Mason Neilan displacement tube type level meter.

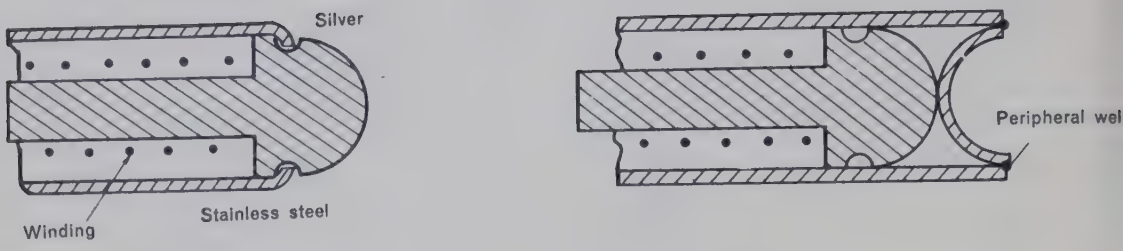
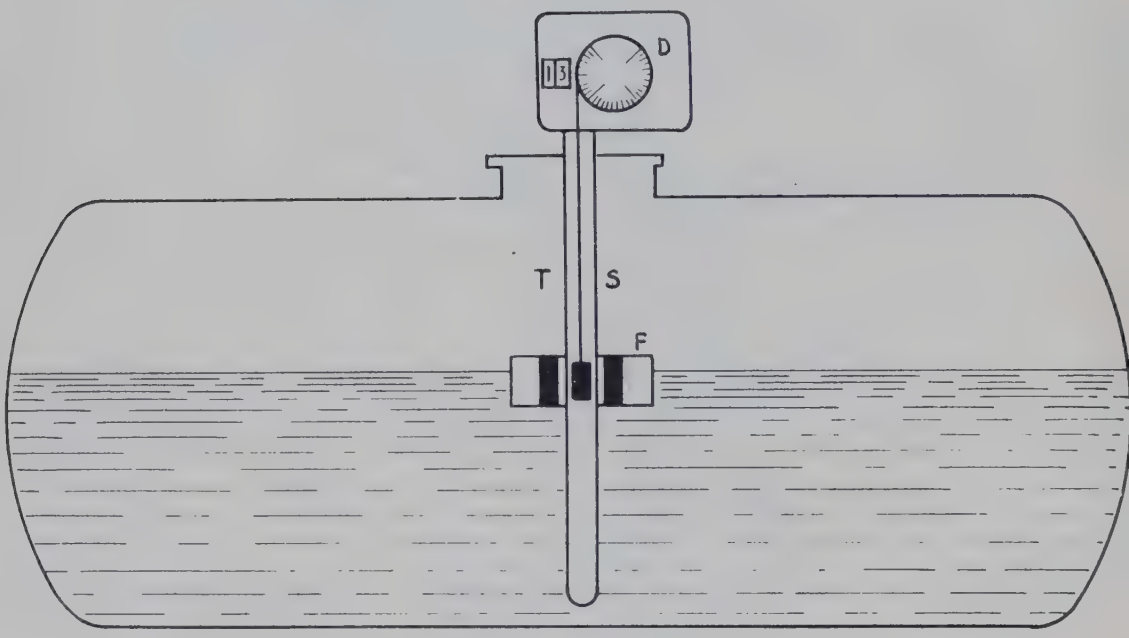


Fig. 32. Foxboro high speed resistance thermometer element.



D. Drum calibrated in inches.
F. Float with primary ring magnet.
T. Closed end tube.
S. Stainless steel transmitting wire.

Fig. 33. Fischer & Porter magnetic follower type level indicator.

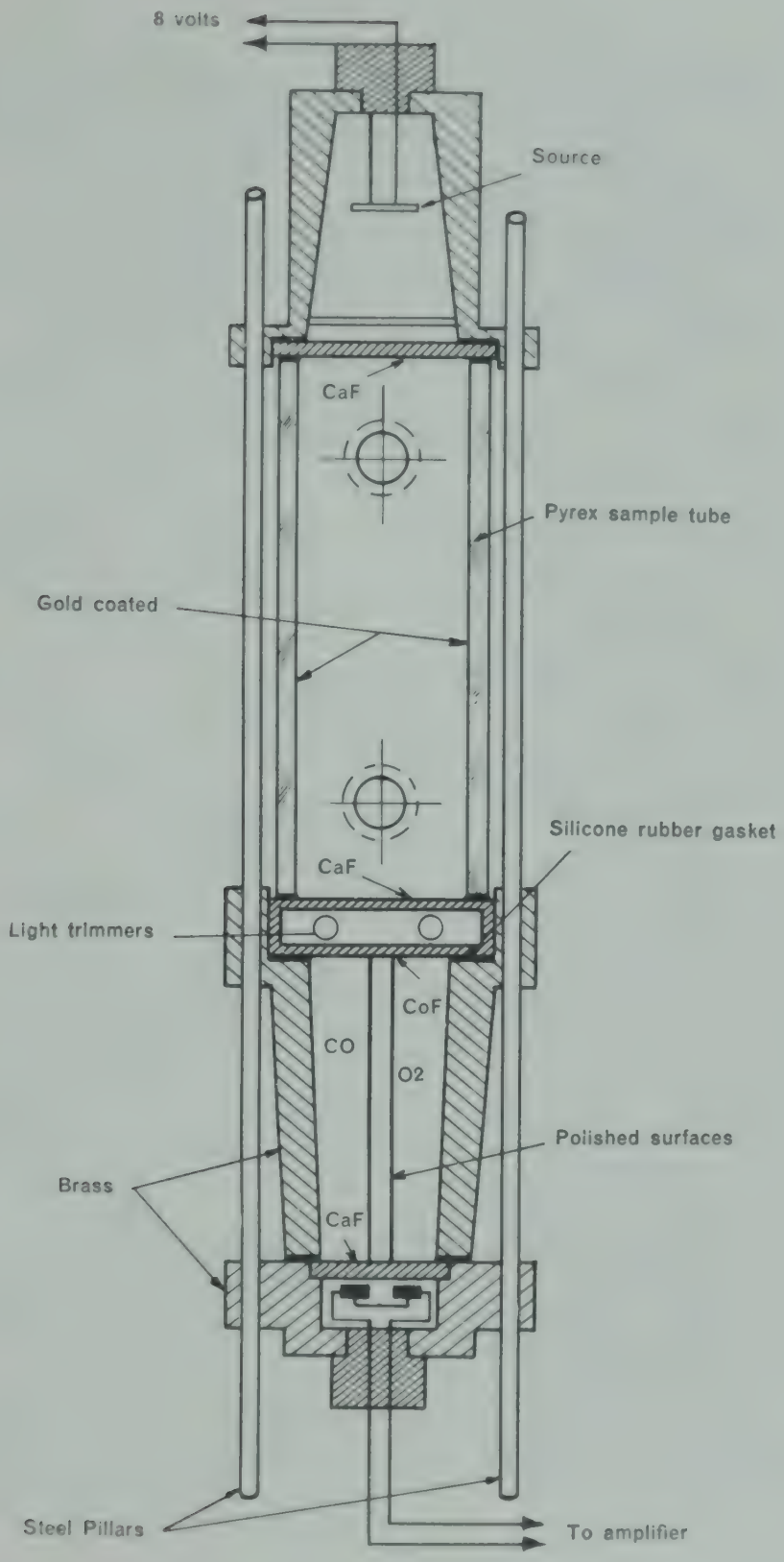


Fig. 34. Leeds & Northrup infra-red gas analyser.

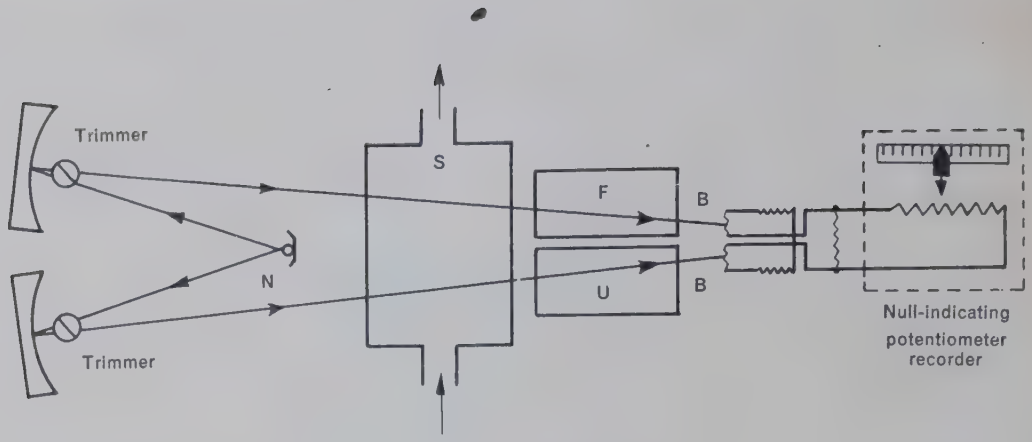


Fig. 35. Baird Associates infra-red gas analyser.

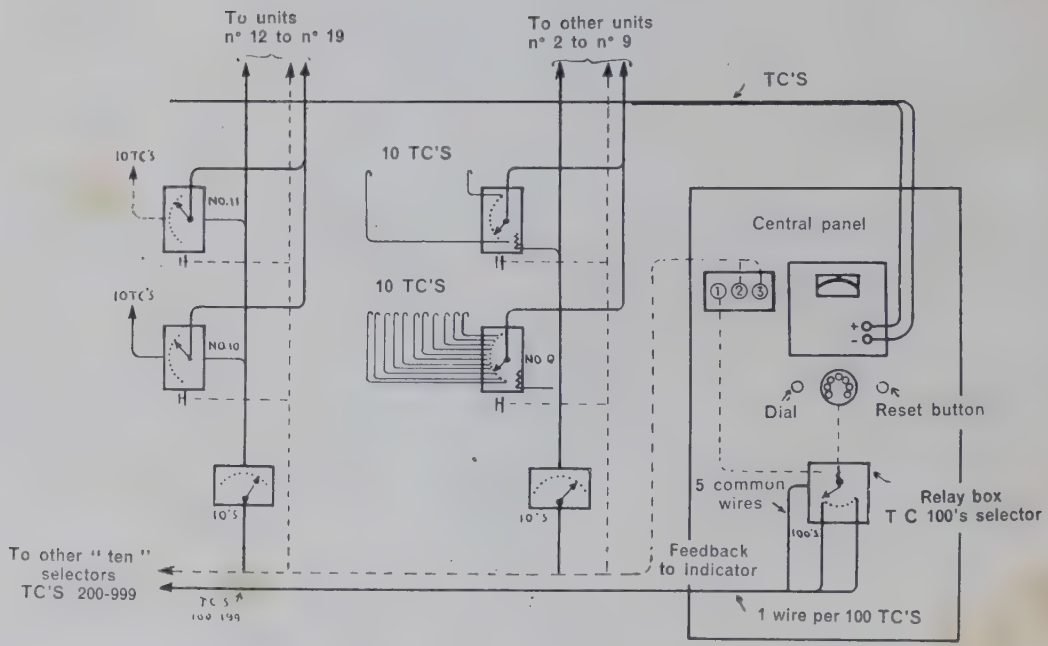


Fig. 36. Dialling system for 1.000 point thermocouple installation.

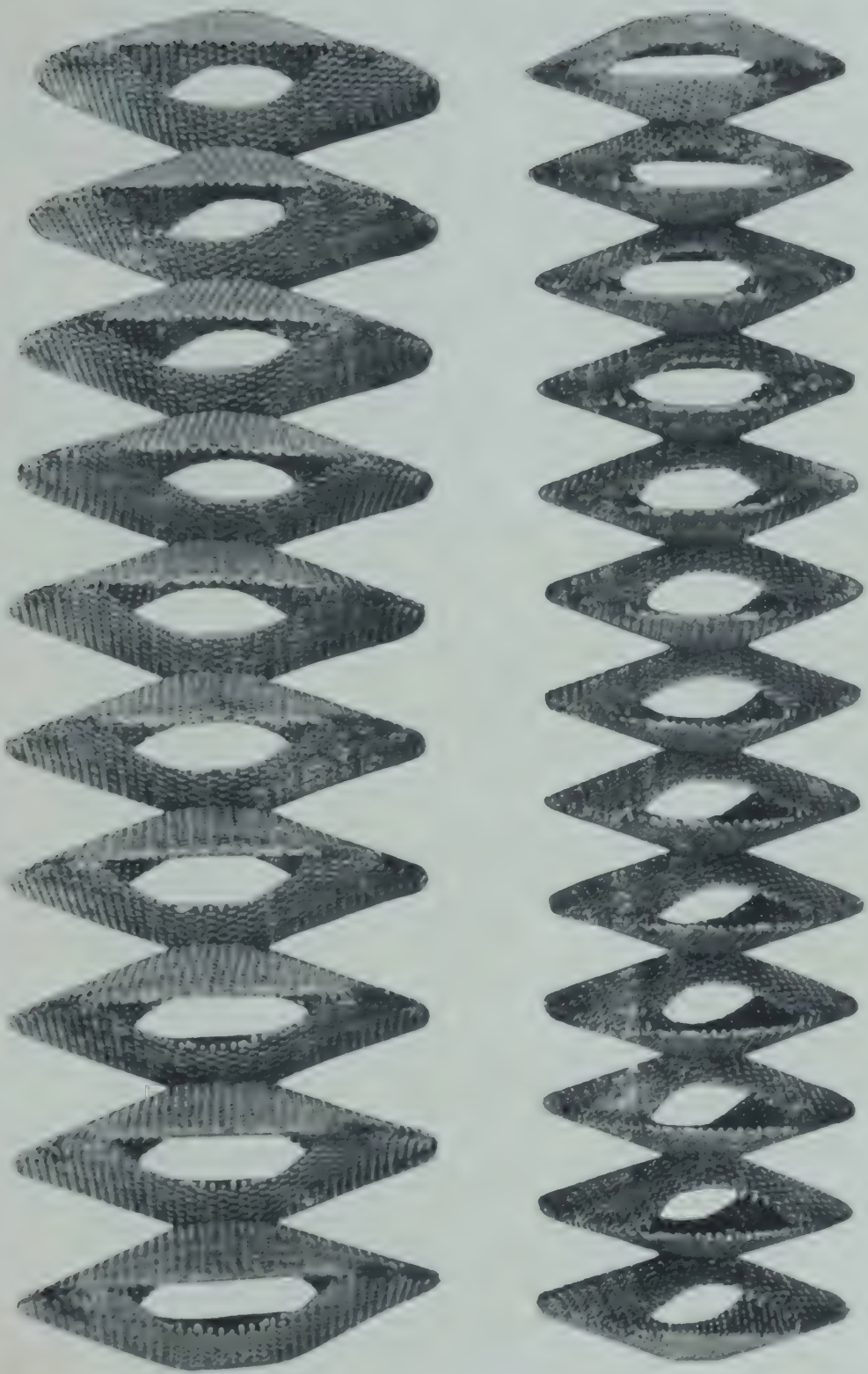


Fig. 37. Stedman Packing. (Figure supplied by Foster Wheeler Corporation.)

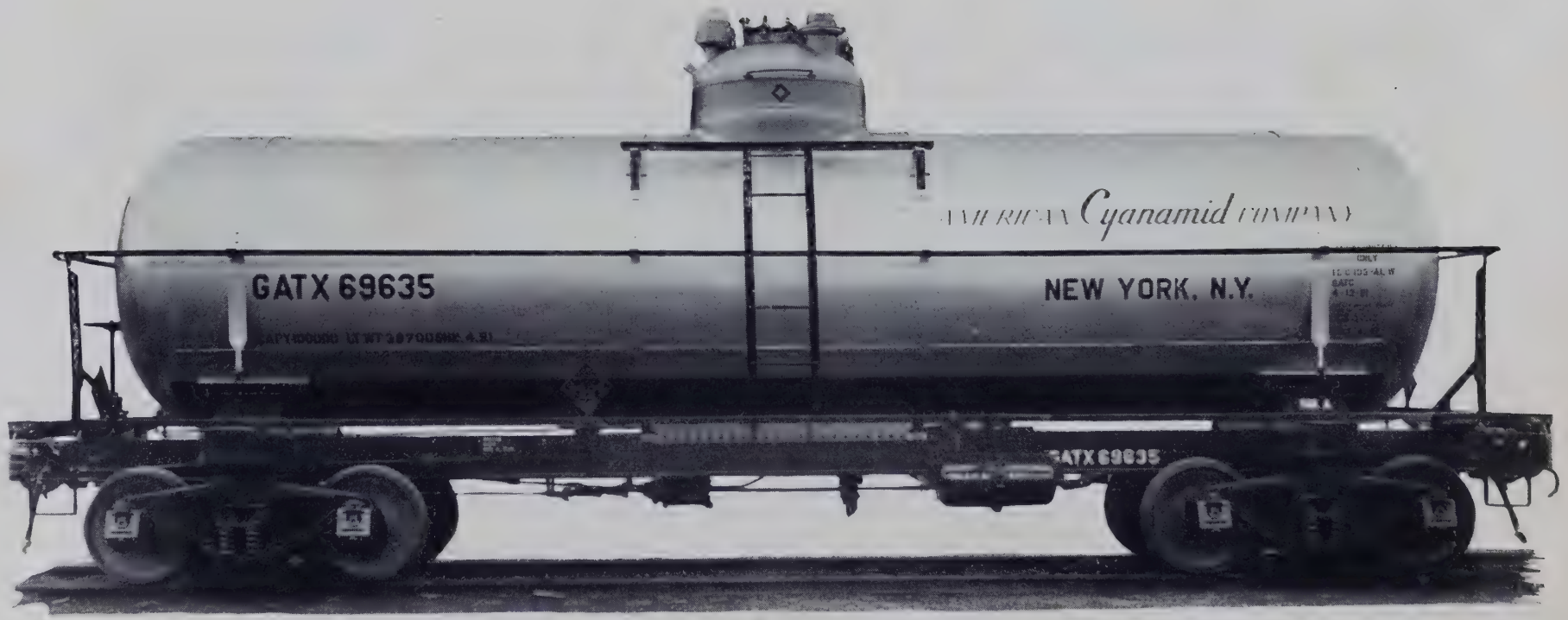


Fig. 38. Aluminium Tank Car.

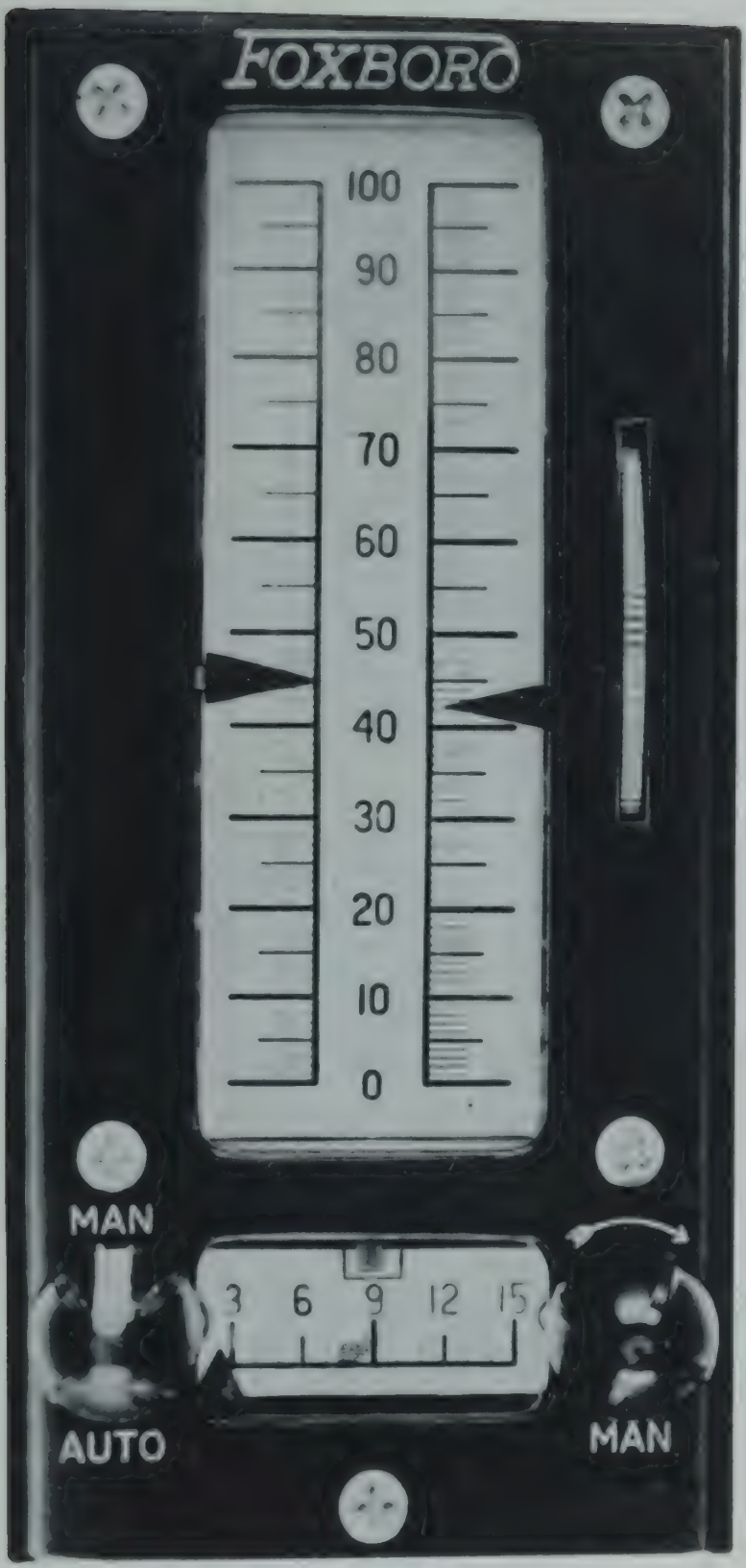


Fig. 39. Foxboro miniature controller.

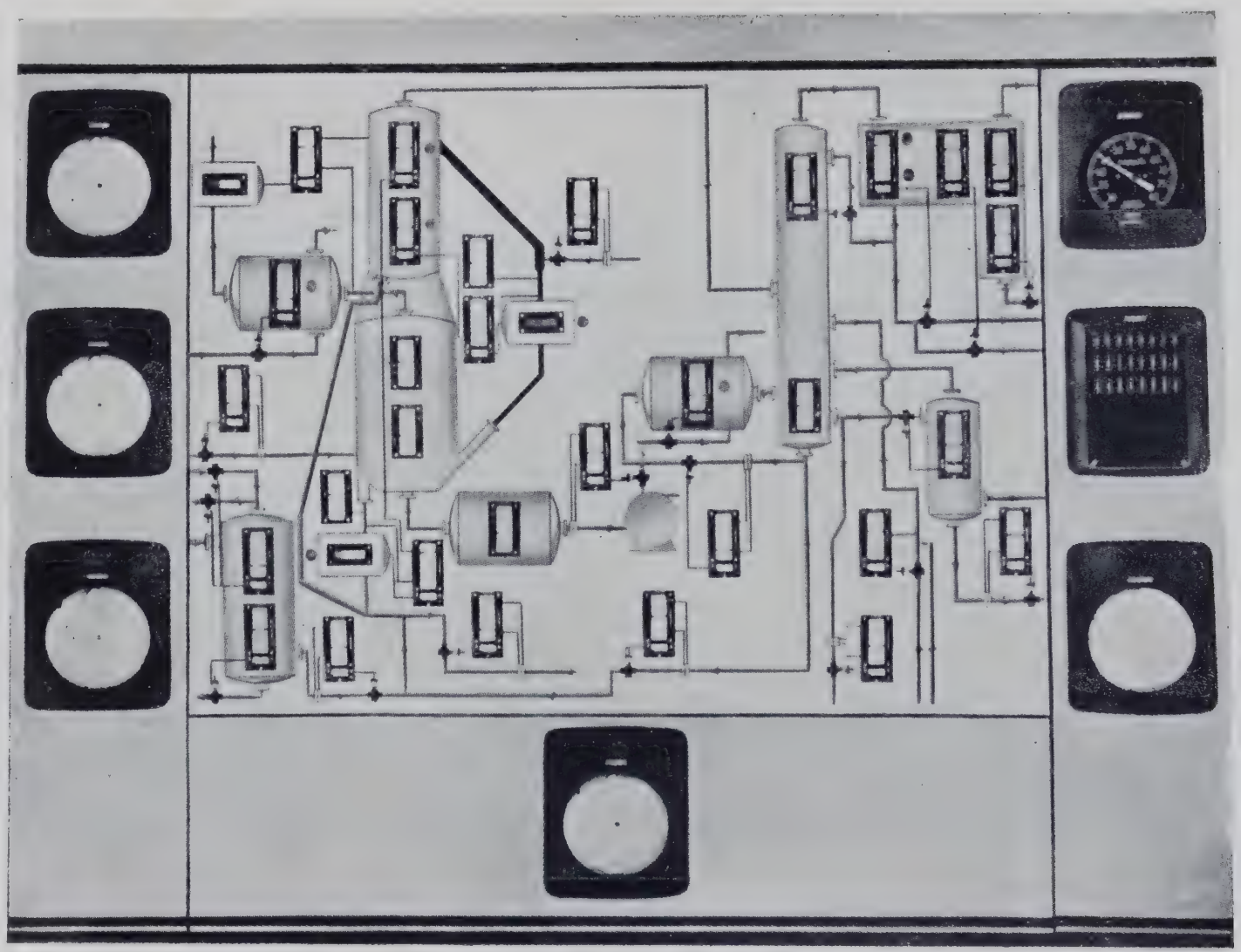


Fig. 40. Panel carrying Foxboro miniature controllers.

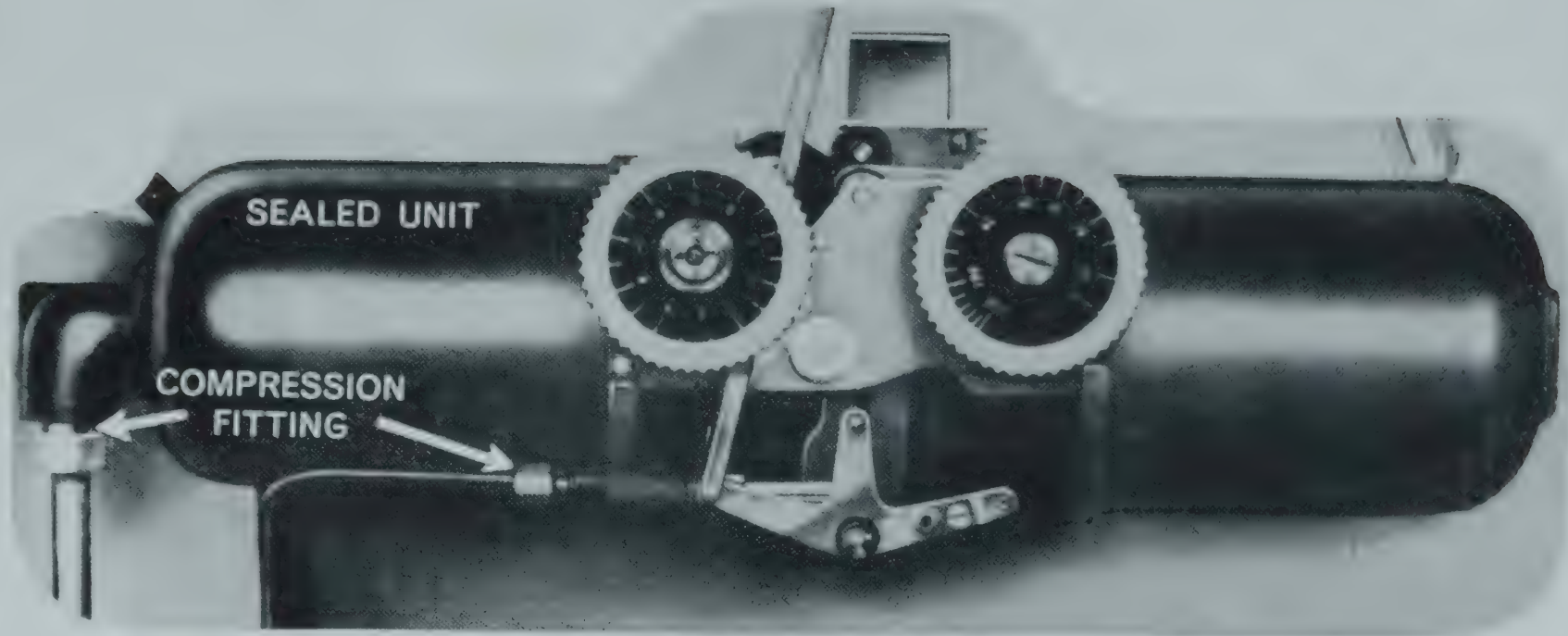


Fig. 41. " Air-O-Line " unit

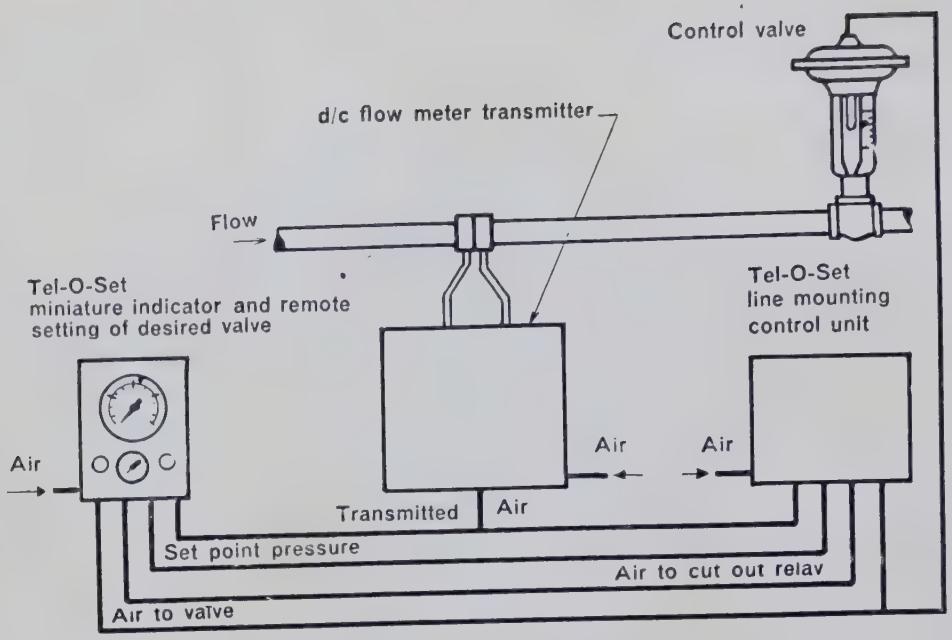
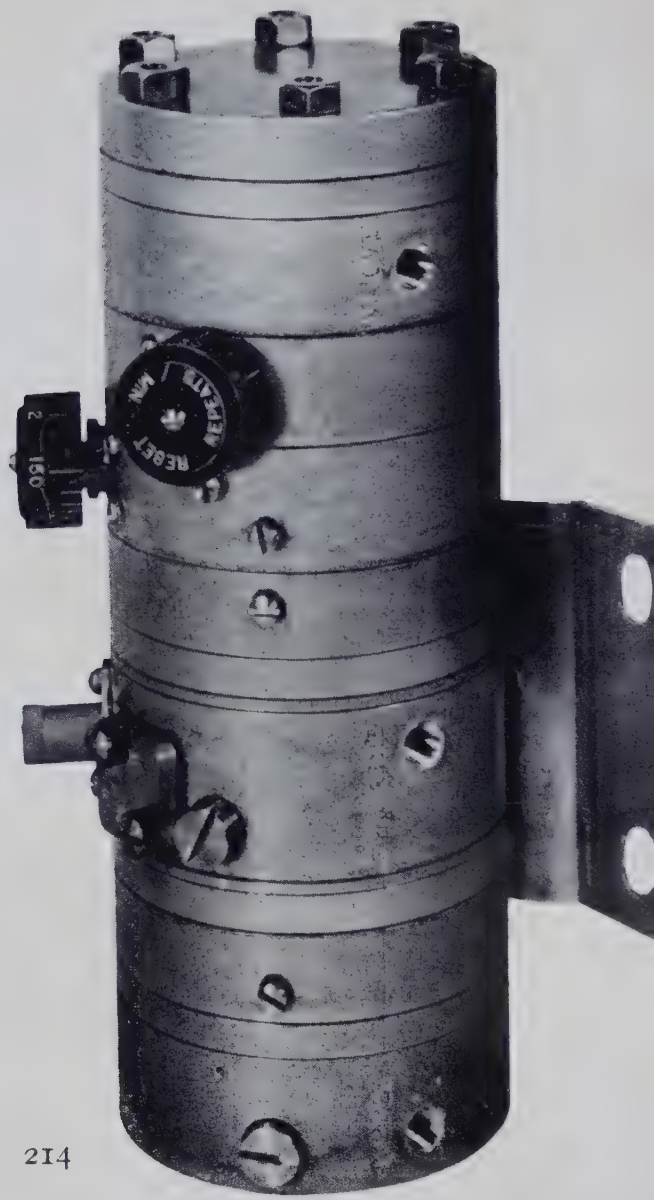
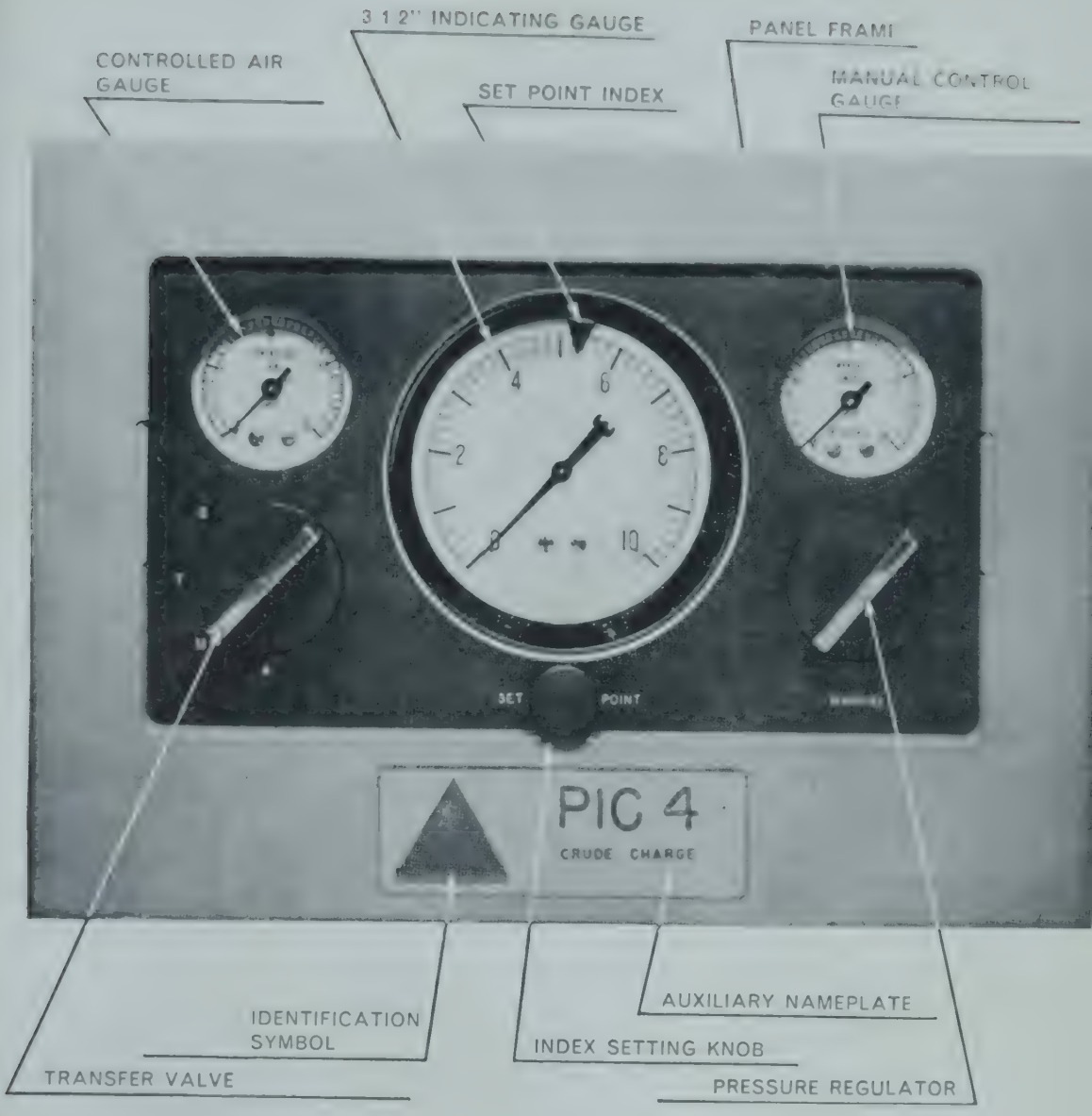


Fig. 42. DIAGRAM OF TEL-O-SET SYSTEM

Tel-O-Set » miniature indicator
remote setting of desired value



Honeywell-Brown " Tel-O-



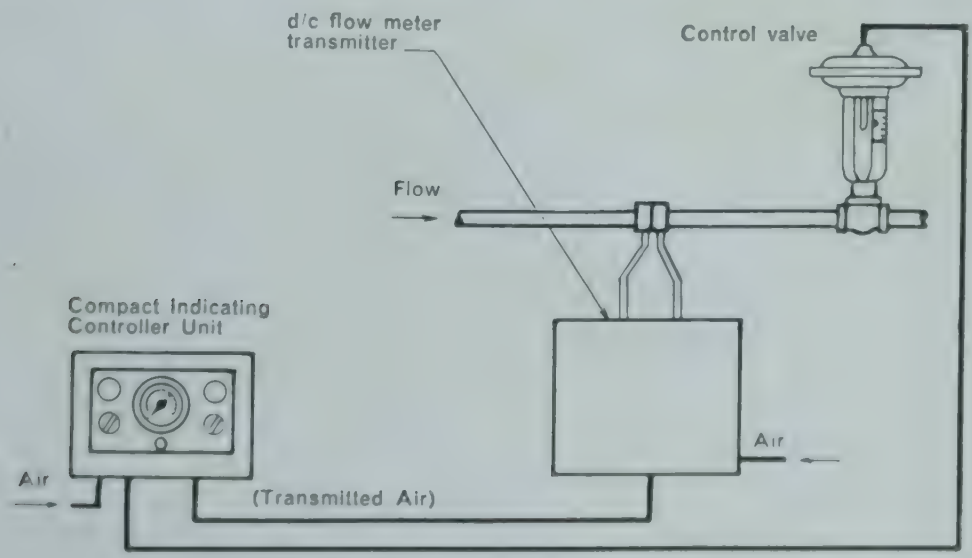


Fig. 43. Compact indicating controller.

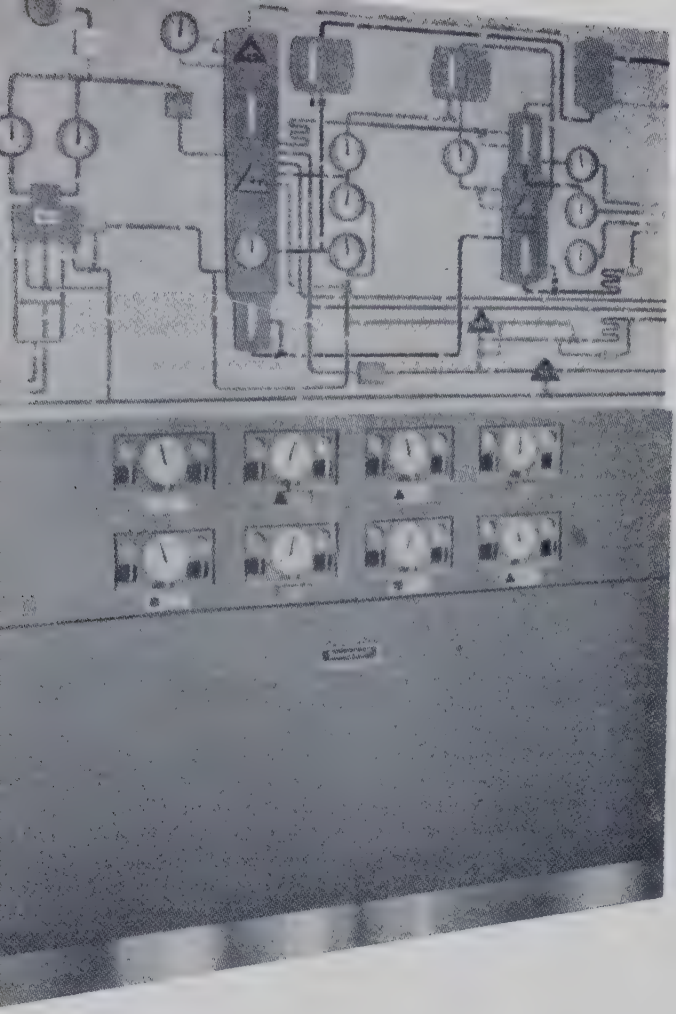


Fig. 44. Section of colour graphic panel showing bank of 8 " C.I.C. " units mounted below flow diagram.

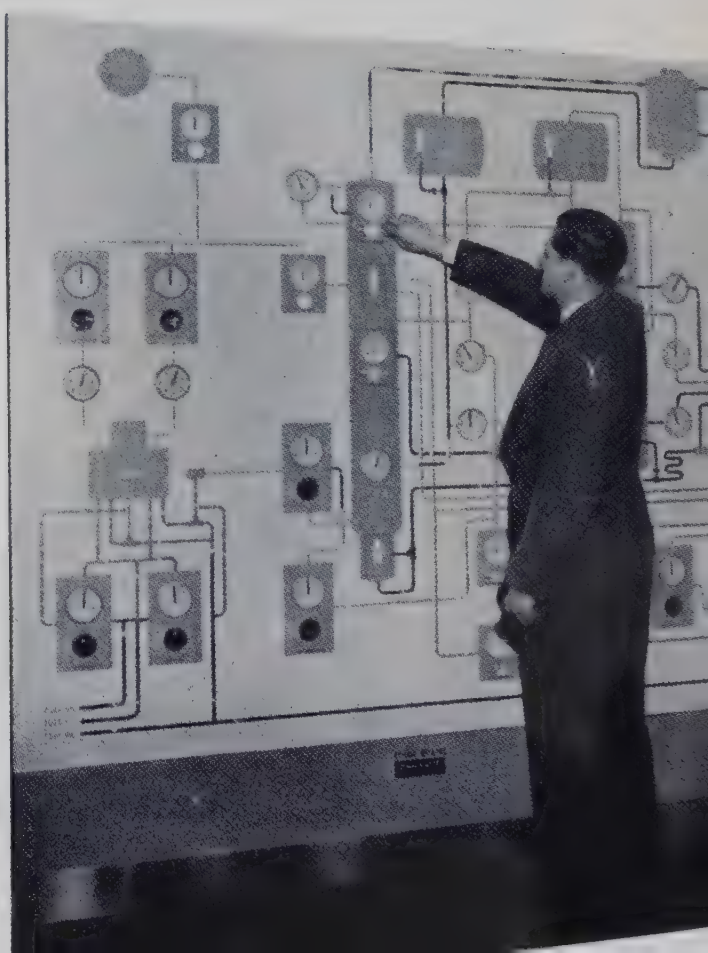
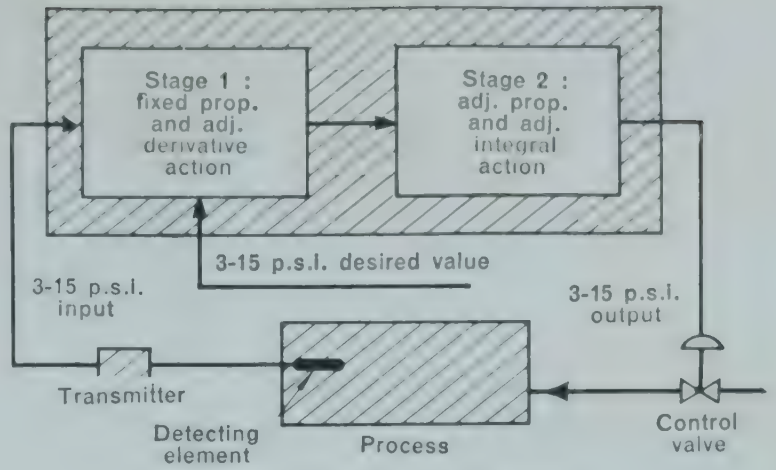
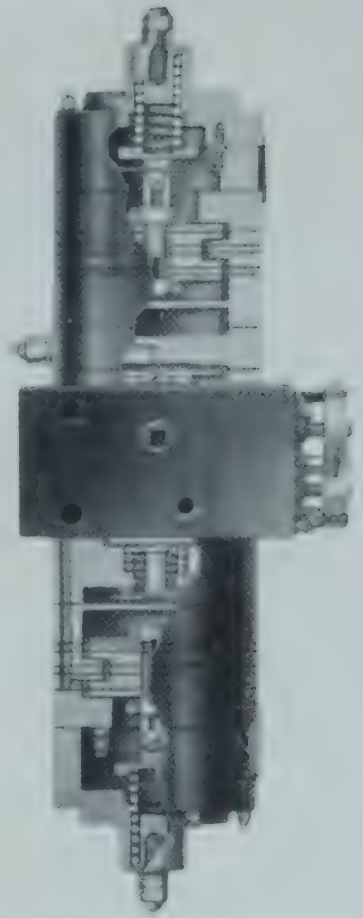


Fig. 45. " Tel-O-Set " units mounted in flow diagrams of colour graphic on panel.

a) Controller front view.



c) Transet tri-act controller system.



b) Controller back view cut away.

Fig. 46. Taylor " Tri-Act " control unit for line mounting.

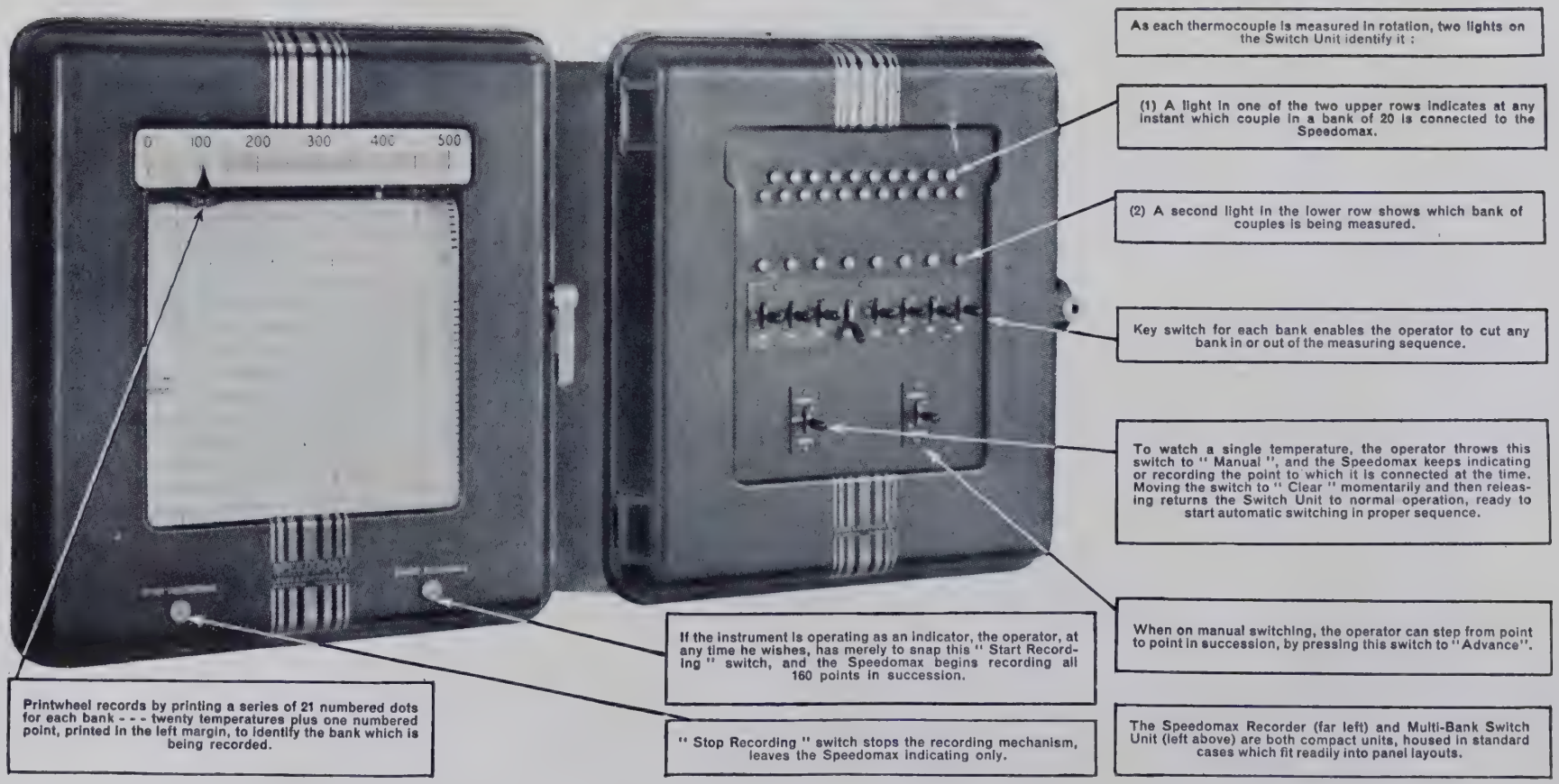

As each thermocouple is measured in rotation, two lights on the Switch Unit identify it :
(1) A light in one of the two upper rows indicates at any instant which couple in a bank of 20 is connected to the Speedomax.
(2) A second light in the lower row shows which bank of couples is being measured.
Key switch for each bank enables the operator to cut any bank in or out of the measuring sequence.
To watch a single temperature, the operator throws this switch to " Manual ", and the Speedomax keeps indicating or recording the point to which it is connected at the time. Moving the switch to " Clear " momentarily and then releasing returns the Switch Unit to normal operation, ready to start automatic switching in proper sequence.
When on manual switching, the operator can step from point to point in succession, by pressing this switch to "Advance".
The Speedomax Recorder (far left) and Multi-Bank Switch Unit (left above) are both compact units, housed in standard cases which fit readily into panel layouts.
If the instrument is operating as an indicator, the operator, at any time he wishes, has merely to snap this " Start Recording " switch, and the Speedomax begins recording all 160 points in succession.
" Stop Recording " switch stops the recording mechanism, leaves the Speedomax indicating only.
Printwheel records by printing a series of 21 numbered dots for each bank - - - twenty temperatures plus one numbered point, printed in the left margin, to identify the bank which is being recorded.
0
100
200
300
400
500

Fig. 47. " Speedomax " arranged to record 160 temperature points.

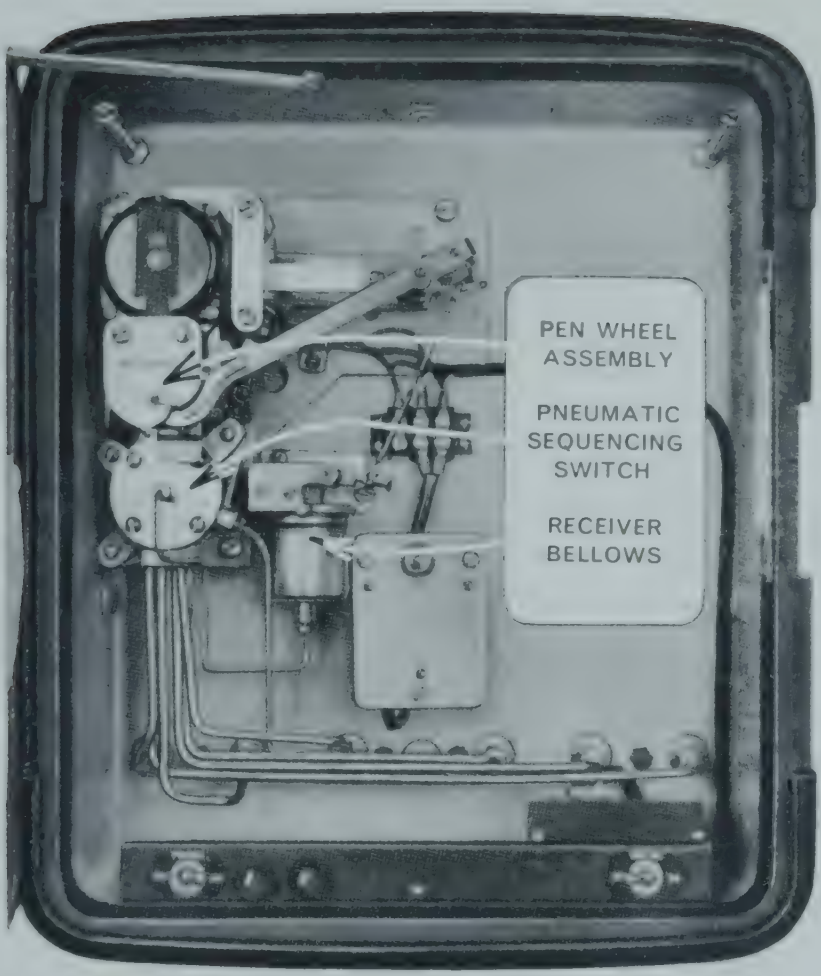


Fig. 48. Foxboro multi-point pressure recorder.

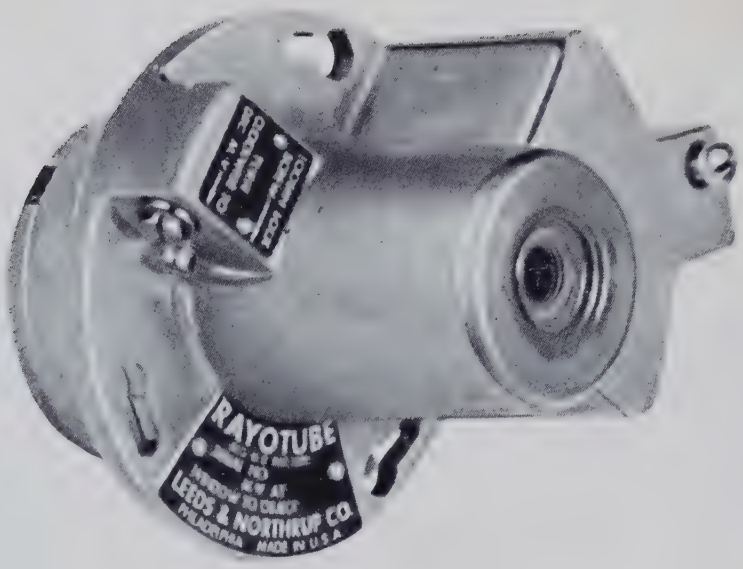
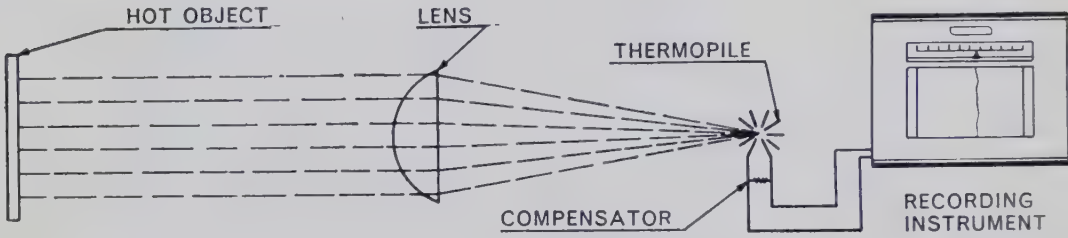
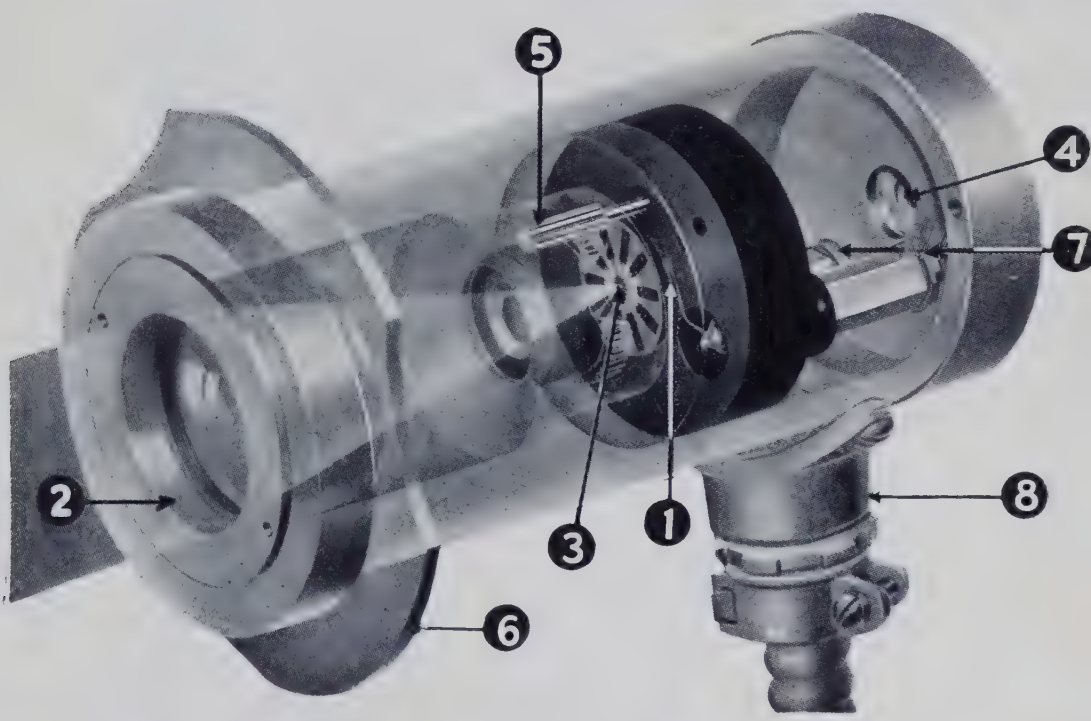


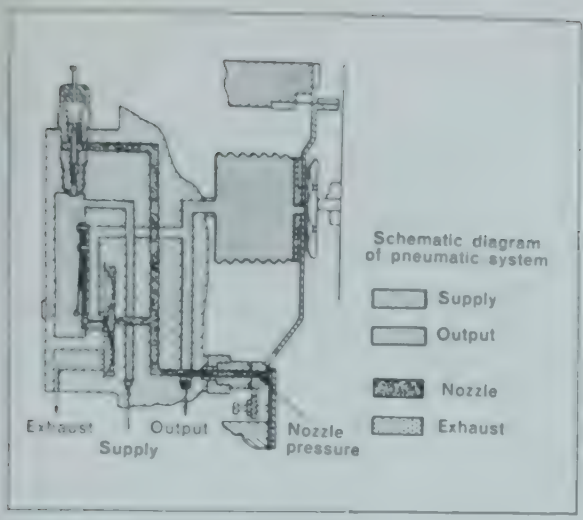
Fig. 49. Leeds and Northrup Rayo tube for surface temperature measurement.





1. Ambient temperature compensating coil.
2. Lens.
3. Thermopile.
4. Sighting lens.
5. Calibration spindle.
6. Mounting r.ng.
7. Terminals.
8. Conduit fitting.

Fig. 50. Honeywell-Brown radiomatic element for surface temperature measurement.



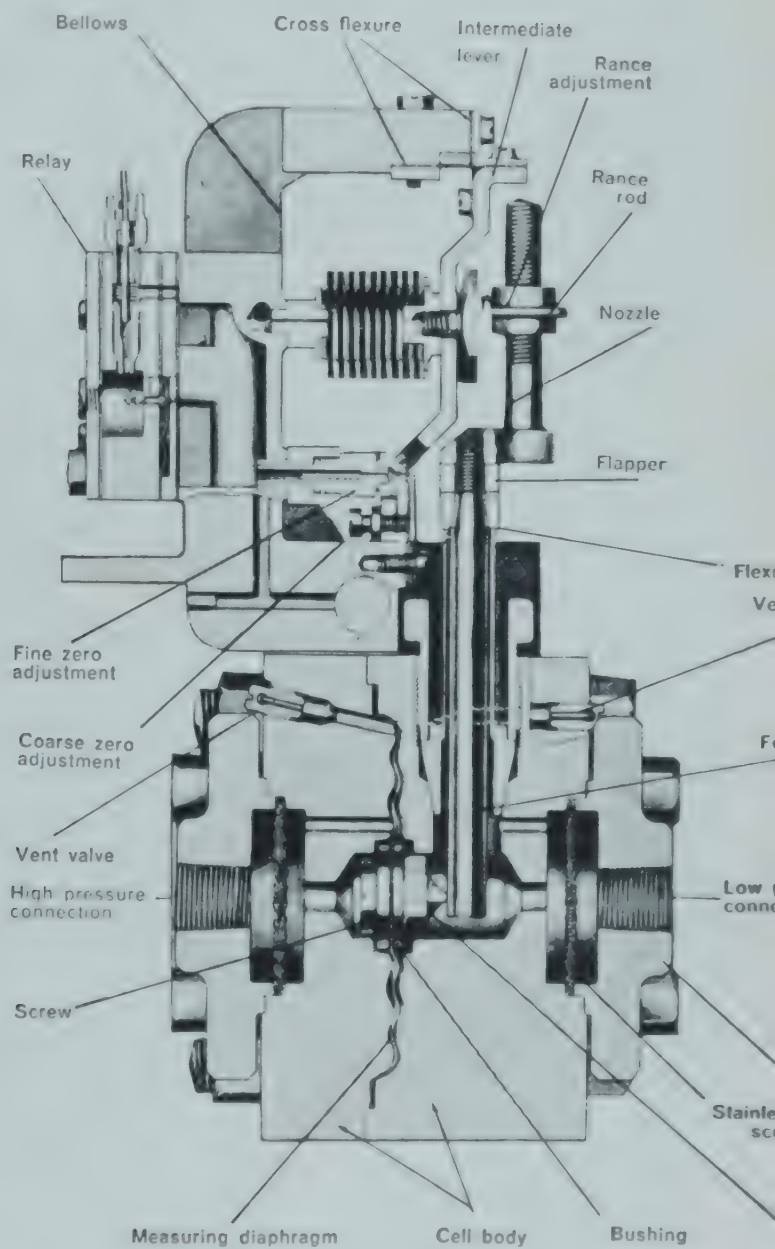


Fig. 51. Foxboro d p cell flowmeter.

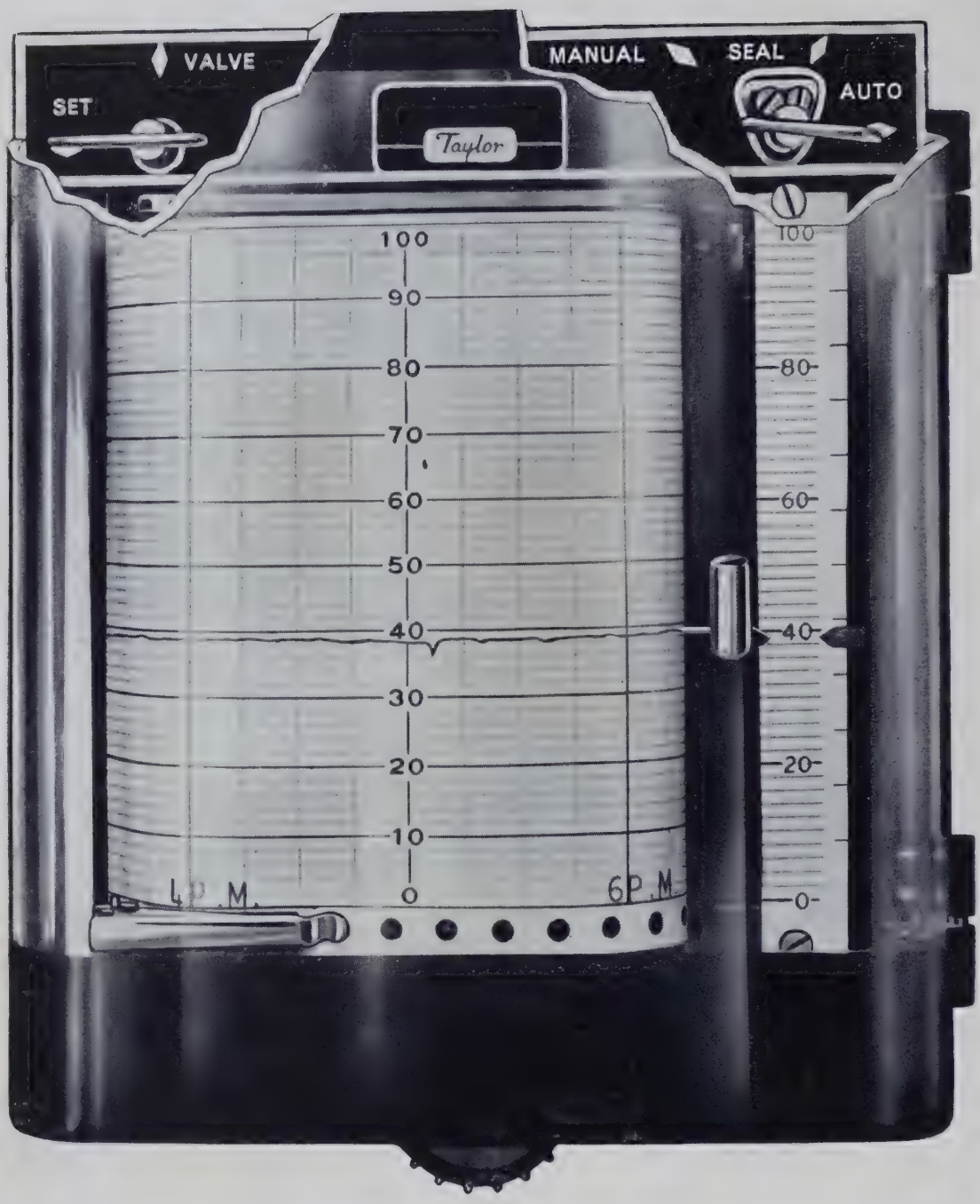


Fig. 52. Taylor Transet miniature recorder.

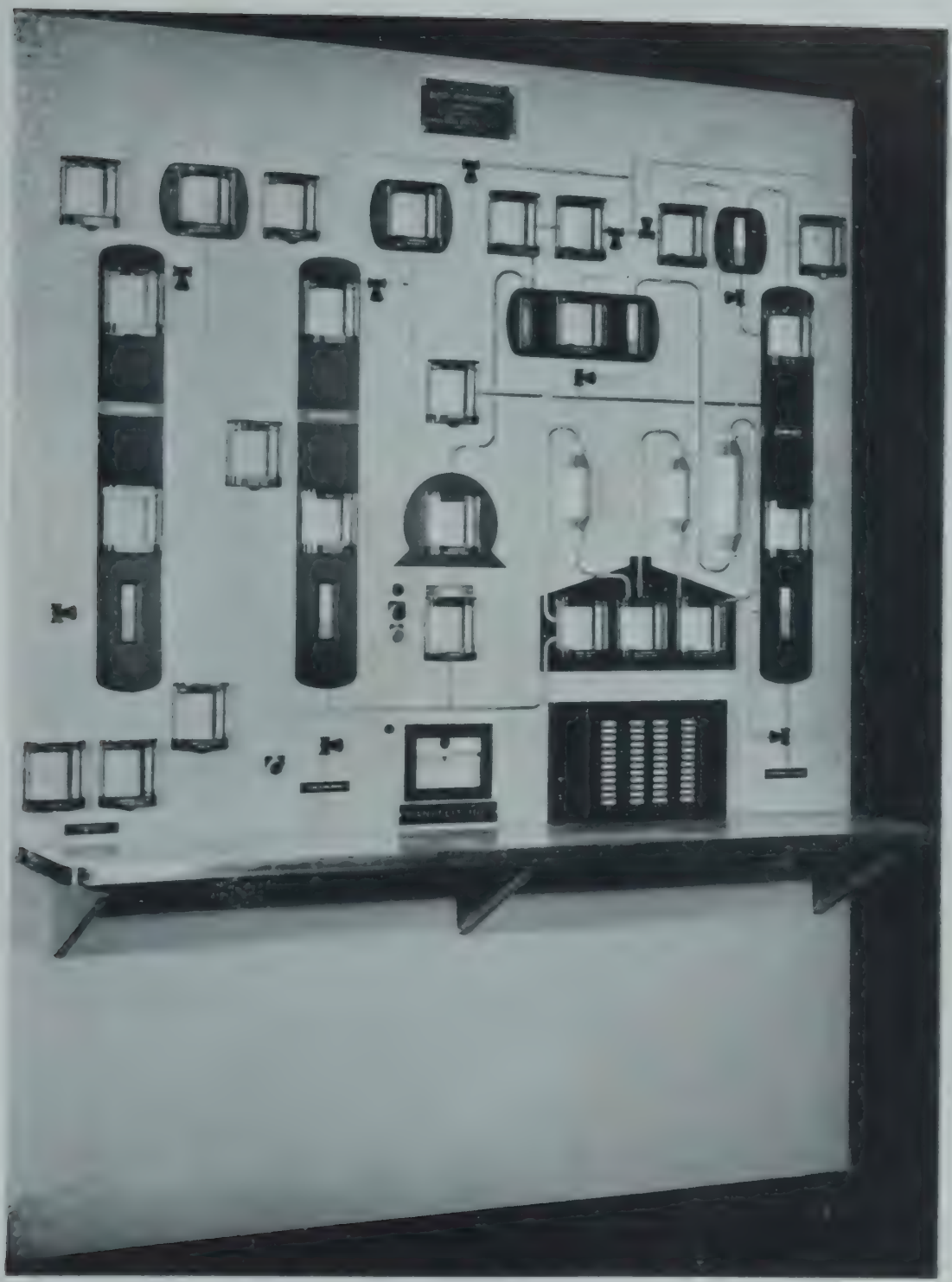


Fig. 53. Graphic panel with Transet recorders.

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